Universidad Complutense Madrid

GRAN TELESCOPIO CANARIAS GTC

MEGARA Exposure Time Calculator.

Users Guide

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Authors:	M. Carmen Eliche Moral, Alexandre Y. K. Bouquin
Revised by:	Ana Pérez Calpena Nicolás Cardiel África Castillo Morales
Approved by:	Armando Gil de Paz Maria Luisa García Vargas

Distribution List:

Name	Affiliation	Date
MEGARA Instrument Team		16/01/2017
MEGARA Science Team		16/01/2017
GRANTECAN		16/01/2017

Acronyms:

AAO	Anglo-Australian Observatory
ADU	Analog to Digital Units
AIV	Assembly, Integration and Verification
AR	Anti-Reflection
CAB	Centro de AstroBiología
CAHA	Centro Astronómico Hispano-Alemán
CCD	Charge-Coupled Device
CSS	Cascading Style Sheet
DAR	Differential Atmospheric Refraction
DC	Dark Current
DIT	Detector Integration Time
ESO	European Southern Observatory
ETC	Exposure Time Calculator
FC	Folded Cassegrain
FLAMES	Fibre Large Array Multi Element Spectrograph
FMPT	Fiber MOS Positioning Tool
FoV	Field of View
FRD	Focal Ratio Degradation
FWHM	Full Width at Half Maximum
GMOS	Gemini Multi-Object Spectrograph
GTC	Gran Telescopio Canarias
GTC-3M	Gran Telescopio CANARIAS 3 Mirrors
GUI	Graphical User Interface
GUAIX	Grupo Ucm de Astrofísica Instrumental y eXtragaláctica
HTML	Hypertext Markup Language
IAA	Instituto de Astrofísica de Andalucía
IAC	Instituto de Astrofísica de Canarias
IFS	Integral Field Spectroscopy
IFU	Integral Field Unit
INAOE	Instituto Nacional de Astrofísica, Óptica y Electrónica
JS	Javascript

LCB	Large Compact Bundle
MEGARA	Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía
MOPSS	MEGARA Observing Preparation Software Suite
MOS	Multi-Object Spectroscopy / Multi-Object Spectrograph
NDIT	Number of DITs
NIR	Near InfraRed
OM	Observing Mode
OT	Observing Template
PPAK	Pmas fiber PacK
PS	Plate Scale
PSF	Point Spread Function
QE	Quantum Efficiency
RON	ReadOut Noise
RP	Robotic Positioner
RSS	Row Stacked Spectra
RUP	Rational Unified Process
SNR	Signal-to-noise ratio
TBC	To Be Confirmed
TBD	To Be Defined
UC	Use-Case
UCM	Universidad Complutense de Madrid
UML	Unified Modelling language
UPM	Universidad Politécnica de Madrid
URL	Universal Resource Locator
UVES	Ultraviolet and Visual Echelle Spectrograph
VLT	Very Large Telescope
VPH	Volume Phase Holographic grating

Change Control

Issue	Date	Section	Page	Change description
1.A	31/05/2011	All	All	First version of document.
1.B	29/09/2011			GTC code and Reference Documents GTC codes added.
1.C	09/01/2012			Section 3 "Overview": – Updated Simulator number of packages and functionality associated to each of them. Section "The Megara Simulator Tool": – Changed the architecture of the Simulator. Now it is divided in the object simulator and the simulator. Section "Flux transformation" – Corrected equation XX. The Resolution R was used instead of the reciprocal dispersion.
2.A	15/03/2014	All	All	– Simulator tool information removed from the present document to another one. – Updated references in list. – Included Summary (current Section 1). – Updated section 2 according to design changes. – Updated definitions in section 3. Inserted definition of voxel. Corrected definition of spaxel throughout the text. – All sections updated according to current modifications to ETC. – Updated outputs in 7.3. – Comments on present status of the tool (CDR version) distributed throughout the text. – Revised text of model equations. – New figures with transmission profiles updated to CDR: 3, 4, 6, 8, 9, and 10. – Updated estimates in Table 10 with current ETC prototype version. – Updated Tables throughout the manuscript.
2.B	31/07/2014	 - 7.1 7.2.4 7.2.5	 1,3 41 44,45 45	Revised CDR issue according to comment: CDR-INT-000 CDR-INT-158 CDR-INT-160 CDR-INT-161 CDR-INT-157 (Acronym added)

2.C	26/01/2015	All	All	References to the SCB fiber bundle are deleted. Section 5 has been updated describing the installation
2.D	09/08/2016	All	All	Sections have been updated according to the new version online
2.E	16/01/17		 All 21, 23 62 72	- Different Sections have been updated. - DIT and NDIT have been replaced by "Exposure time per frame" and "Number of exposure frames" (LAR-INT-031) - Equation fixed (LAR-INT-033) - Section 8.2 "Comparison with other facilities" has been moved as an Appendix. (LAR-INT-034) - Section 7.4.3 "Moffat Point-Spread-Function for a more accurate SNR" has been added.

Applicable (A) and Reference (R) Documents

Nº	Document Name	Code
R.1	Rational Unified Process 5.1	No code
R.2	*"The Unified Modelling Language"*. Version 1.1 - Object Management Group	No code
R.3	*"UML for Managers"*. Jason Gorman 2005 e-book available at: http://www.codemanship.co.uk/parlezuml/e-books/umlformanagers/	No code
R.4	MEGARA Functional Requirements Document	RQ/IN-MG/001
R.5	MEGARA Conceptual Design. Overview	TEC/MEG/009
R.6	MEGARA. Feasibility study for an intermediate resolution spectrograph for the GTC	TEC/MEG/001
R.7	GTC Services to the Instruments (DCI/INST/0053-R)	GTC/MEG/007
R.8	Science Instruments - Support Elements (DCI/STMA/0037-R)	GTC/MEG/010
R.9	Folded Cassegrain Instrument Rotator - Science Instrument (DCI/TELE/0057-R)	GTC/MEG/002
R.10	Interface Folded Cassegrain Instrument Rotator - Instrument (Drawing) (DR-I-IN-TL-007/001)	GTC/MEG/011
R.11	Instrumentation - Telescope Structure (DCI/STMA/0018-R)	GTC/MEG/009
R.12	MEGARA Fiber MOS Conceptual Design	TEC/MEG/016
R.13	"*Communication in the presence of noise*", C.E. Shanon, 1949. Proc. Institute of Radio Engineers, vol. 37, no. 1, pp. 10-21	No code
R.14	GTC Control System Software Standards (ESP/CTRL/0045-R)	GTC/MEG/004
R.15	MEGARA Observing Modes	TEC/MEG/005
R.16	FRIDA Operational Concepts Definitions, Issue 2.B	FR/UR-SC/007
R.17	Sánchez, S. F. : '*E3D, the Euro3D visualization tool I: Description of the program and its capabilities*'. 2004, AN, 325, 167.	No code
R.18	Sánchez, S. F.: '*Techniques for reducing fiber-fed and integral-field spectroscopy data: An implementation on R3D*'. 2006, AN, 327, 850	No code
R.19	"*Volume Phase Holographic Gratings*". S. Barden, 1998. NOAO Newsletter - Number 54	No code
R.20	"*Optical Astronomical Instrumentation*". S. Barden, J. Arns, & B. Colburn, 1998, Ed.: Sandro D'Odorico, Proc. SPIE, Vol. 3355, p. 866-876	No code
R.21	MEGARA Control System. Stakeholder Needs (III). Observing Program Management System	TEC/MEG/036
R.22	MEGARA Control System - Use Cases Model Survey (III). Observing Program Management Subsystem (OPMS)	TEC/MEG/040

R.23	"*Exposure Time Calculators – Formula Book*". A. Modigliani, 2009	No code
R.24	"*La Palma night-sky brightness*". C.R.Benn & S.L. Ellison, 1997. La Palma technical note 115	No code
R.25	"*The Definition of Dark, Grey and Bright Time at ING*". I. Skillen, 2002. ING Technical Note 127.	No code
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R.29	CAHA/PMAS exposure time calculator. S. Sánchez, 2006. http://www.caha.es/sanchez/pmas/calculator/pmas_etc.php	No code
R.30	GIRAFFE Exposure Time Calculator, versión 3.2.7ª (March 4, 2009). http://www.eso.org/observing/etc/bin/gen/forms?INS.NAME=GIRAFFE++INS.MODE=spectro	No code
R.31	"*Absolute flux calibrated spectrum of Vega*". L. Colina, R. Bohlin, & F. Castelli, 1996. Instrument Science Report, CAL/SCS-008	No code
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R.39	MEGARA Spectrograph Conceptual Design	TEC/MEG/006
R.40	MEGARA Detector and DAS Preliminary Design	MEG/TEC/051
R.41	"*The Importance of Atmospheric Differential Refraction in Spectrophotometry*". Filippenko, A. V. 1982, PASP, 94, 715	No code
R.42	*"Spherical astronomy"*. Green, R.M. 1985, Cambridge University, p.87	No code
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R.45	"*Optical Refractive Index of Air: Dependence on Pressure, Temperature and Composition*"**.** Owens, J.C., 1967, Appl.Opt. 6, 51	No code
R.46	"*E2V CCD231-84 Back Illuminated Scientific CCD Sensor*" Document description.E2V Technologies (UK) limited, 2009. A1A-765136 Version 2 (July 2009). http://www.e2v.com	No code
R.47	"MEGARA PSF Simulations: Spectral Resolution and Cross-talk effects."	TEC/MEG/076
R.48	"MEGARA Preliminary Design: Instrument Overview"	TEC/MEG/059
R.49	MEGARA Detailed Design: Flux Homogeneity, Issue 1.B	TEC/MEG/117
R.50	*FITS: A Flexible Image Transport System*, Wells, D. C., Greisen, E. W., and Harten, R. H., 1981. A&AS, 44, 363	No code
R.51	MEGARA Detailed design: Instrument Overview, Issue 1.A	TEC/MEG/106

R.52	MEGARA Detailed Design:Transmission, Issue 1.C	TEC/MEG/055
R.53	RGO/La Palma Technical Note no. 31, Atmospheric *Extinction at the Roque de los Muchachos Observatory, La Palma*, D L King (RGO), 6 September 1985	No code

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R.21	MEGARA Control System. Stakeholder Needs (III). Observing Program Management System	EXT/UCM/1747-R
R.22	MEGARA Control System - Use Cases Model Survey (III). Observing Program Management Subsystem (OPMS)	EXT/UCM/1751-R

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R.51	MEGARA Detailed design: Instrument Overview, Issue 1.A	TBD

R.52	MEGARA Detailed Design:Transmission, Issue 1.C	EXT/UCM/1741-R
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INDEX

1. SUMMARY

This document presents the Users Guide of a software component of the MEGARA Observing Preparation Software Suite (MOPSS hereafter): the MEGARA Exposure Time Calculator (ETC). The MOPSS shall provide the tools needed to assist observers to plan their observations in an optimum way. In the following sections, a detailed description of the physical model of the MEGARA ETC and its usage is provided.

The MEGARA ETC is originaly a stand-alone software package that has now been ported to an online-accessible version. This tool has already been implemented on-line (http://tajox.fis.ucm.es:8080/etc/form) to facilitate the definition and assessment of the MEGARA Science Cases. Newer versions of it are being developed at this time to incorporate new predictions and improvements in the SNR estimations. Therefore, this document will be updated.

2. INTRODUCTION

MEGARA (Multi-Espectrógrafo en GTC de Alta Resolución para Astronomía) is an optical Integral-Field Unit (IFU) and Multi-Object Spectrograph (MOS) built for the GTC 10.4m telescope in La Palma.

The MEGARA IFU mode offers a fiber bundle covering 12.5x11.3 arcsec^2 with a spaxel size of 0.62 arcsec (Large Compact Bundle; LCB, which uses 100μm-core optical fibers).

The MEGARA MOS allows observing up to 100 objects in a region of 3.5' x 3.5' around the IFU bundle [R.4-R.6]. Eight of these bundles (56 fibers) are devoted to the determination of the sky during the observation with the LCB IFU and are placed fix in focal plane. Each of the MEGARA MOS positioners can place a mini-bundle of 7 fibers (1.6" of diameter in total on the sky). The positioning of the fiber optical bundle is performed by combining the interpolation of two rotations. The interpolation between rotation 1 and rotation 2 allows covering the patrol area assigned to each robotic positioner.

The IFUs and the robotic positioners (RPs) along will the interface with the optical fibers are placed at the Folded-Cassegrain focus of the GTC 10.4-m telescope.

In the case of the MEGARA Spectrograph the optical elements are placed on an optical table located at the Nasmyth A platform of GTC. Apart from the "baseline" optical elements, such as the collimator and the camera, there is a mechanism that automatically interchanges 11 Volume Phase Holographic gratings (VPHs), a mechanism that provides focus adjustment, a mechanism that allows switching between pseudo-slits and a rotating shutter.

MEGARA uses VPHs as dispersive elements [R.4-R.7]. The wavelength coverage is 3,650-10,000 Å, with a spectral resolving power from 6,000 to 20,000 in the LCB and MOS modes, depending on the set of VPHs available at the VPH Wheel. The whole optical spectrum is covered at low resolution, or at medium and high resolutions depending on the selected VPH.

MEGARA is a collaborative project of an international consortium comprising:

1. The Universidad Complutense de Madrid (UCM, Spain), as the leading institution.
2. The Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE, México).
3. The Instituto de Astrofísica de Andalucía (IAA-CSIC, Spain).
4. The Universidad Politécnica de Madrid (UPM, Spain).

Main private contractors are FRACTAL (Spain), AVS (Spain), GMV (Spain), Wasatch Photonics (USA), and SEDI (France).

The MEGARA ETC, the Simulator, the MEGARA Fiber MOS Assignment Tool (FMAT) and the MEGARA Fiber MOS Positioning Tool (FMPT) are software packages contained in the MOPSS system. The MOPSS provides the tools needed to assist observers to plan their observations in an optimum way. In the following sections, relevant information to the user of the ETC is provided.

The main objectives of each tool are the following:

1. The MEGARA ETC tool simulates the signal-to-noise ratio (SNR) to be obtained for the continuum or for a specific emission line of an input source. The tool derives also the change in SNR vs. wavelength in the case that a source spectrum from the database is provided as input, in one voxel or from one or several spaxels. The tool can also estimate the limiting magnitude of flux of a line or the continuum for an input SNR and exposure time, as well as the exposure time to get a final SNR on a given source line or continuum.

2. The MEGARA Simulator tool is intended to create a set of images simulating the output of the MEGARA instrument depending on the observational strategy for a given input source. The tool includes the expected sky contribution to the final spectrum, considers the wavelength range of the selected MEGARA configuration, and simulates the output observation of the provided input source as a function of the input observational parameters chosen by the user. The Simulator returns a MEGARA frame in FITS format with the simulated spectra corresponding to each spaxel from any input flux calibrated spectrum.

3. The FMAT allows the user to prepare a Configuration Block Set (CBS) composed for several Configuration Blocks (CBs) for the MEGARA MOS mode by assisting the user in the assignment of their sources to the different in-use robotic positioners of the MEGARA MOS (up to 92 positioners). FMPT estimates the motion sequences to be done by the RPs (simultaneous and subsequent) to ensure no collisions among adjacent positioners while minimizing the time to configure all of them.

The former two tools must account for the flux distribution of the input source, the instrument configuration, and the atmospheric conditions of the run, as well as for the observation strategy to use.

This document presents the Users Guide of the MEGARA ETC.

3. DEFINITIONS

3.1. Airmass

Airmass is a dimensionless parameter related to zenital angle z (which is the arc of a vertical circle between the zenith and the target's position on the celestial sphere, measured from the zenith through 90º). Airmass is simply sec(z)=1/cos(z), and it is related to the amount of atmosphere that the ray of light has to cross in plan-parallel approximation. For zenith (z=0º), its value is one (where the absorption is minimum), and increases to infinite at the horizon (z=90º), where the absorption is maximum (but not infinity, as the plane-parallel approximation is no longer valid).

3.2. Bias Frame

The value of the pixels of a CCD image with zero exposure time include a mean offset inserted to avoid negative count levels in any pixel of the image (also known as mean bias level or sometimes simply bias level), an individual pixel-to-pixel variation (that corresponds to changes in the bias level), and the readout noise (§3.18). A bias frame is the CCD image resulting from a direct readout of the detector with an exposure time set to zero and no illumination (i.e., with the shutter behind the pseudo-slit of the spectrograph closed).

3.3. Exposure time per frame

It is the integration time (in seconds) needed to obtain a single detector frame.

3.4. Fiber

A MEGARA fiber has a circular core section of 100μm. The fiber is appended to a micro-lens with a hexagonal section exposed to the light, responsible of changing the focal ratio coming from the telescope to the one required by the spectrograph [R.5, R.12]. The hexagonal section of the micro-lens is inscribed in a circle of projected diameter D_{eff} = 0.62 arcsec in the LCB and MOS (see the definition of *spaxel* in §3.20). The side of the hexagon L_{spaxel} is equal to the radius of the circle (see *Figure 1*). The distance between the centers of adjacent microlenses is two times the apothem (a). The fiber is appended to this hexagonal region that is being over-illuminated to ensure a uniform illumination in the whole circular section of the fiber and a homogeneous illumination from fiber to fiber. This is to the penalty of small light losses, which imply an effective transmission of 83.5% for the 100μm-core fibers [R.48] [R.49].

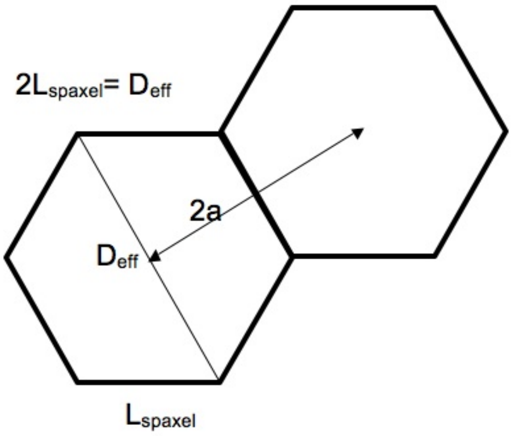

Figure 1: *Layout of two MEGARA micro-lenses. The circular fiber is behind each hexagonal region, at a given distance, being over-illuminated [R.49]. The distance between centers is twice the apothem.*

3.5. Flatfield Frame

It is a frame taken with a uniform illumination. It contains information about:

- Photo-Response Non-Uniformity.
- Vignetting of optical elements.
- Interference fringing within detector.
- Cosmetic defects (dark pixels or columns).
- Contamination (dust near focal plane or optical train).
- Thermal emission of the telescope plus the instrument system.

3.6. Frame

A frame (or image) is the number matrix resulting from reading the CCD pixels after a given exposure of it. This matrix is usually saved into a FITS file format [R.50].

3.7. Linear Dispersion

The linear dispersion associates wavelengths and positions of the lines in a spectrum. In MEGARA, due to distortions related with the dispersive elements, the relationship between the wavelength of the spectral lines and the positions they appear in is not linear. In order to take this into account and perform the wavelength calibration, an *n*-degree polynomial is used (with *n* typically 3 or 5).

$$\lambda(x) = \sum_{i=0}^{n} a_i x^i \quad . (1)$$

The ETC does not account for this effect, as it does not consider other effects typical of CCD frames, such as bias, flat-field or vignetting, but it considers the change in linear dispersion at each wavelength for each VPH (the linear dispersion changes slightly across the wavelength range of the VPHs to keep the spectral FWHM constant by design [R.51]).

3.8. Nyquist-Shanon theorem

A fundamental result in the field of information theory, in particular in signal processing, is the Nyquist-Shanon theorem, which in its Shanon's version states that [R.13]: "If a function *x(t)* contains no frequencies higher than *B* hertz, it is completely determined by giving its ordinates at a series of points spaced *1/(2B)* seconds apart".

Translated to the spatial sampling of a signal in the detector plane, the previous theorem implies that, in the case that the minimum resolution element of the detector is a pixel length in each detector dimension, at least 2 pixels in each detector dimension are required in order to sample correctly the input signal. So, in this case, the minimum resolution element on the detector would be 2×2.

In the case of MEGARA, this theorem states somehow differently, accounting for the fact that the minimum spatial resolution element is the projection of one fibre (4 pixels), and the minimum spectral resolution element is set by the FWHM of each VPH (4 pixels, [R.51]. If each resolution element is sampled with at least 2 pixels, the Nyquist-Shanon theorem is fulfilled. Consult §3.20 for more details.

3.9. Number of exposure frames

It is the number of independent detector frames (each one with the number of seconds set by "Exposure time per frame") obtained sequentially at a fixed position.

3.10. Observing Strategy

Using the same GTC/MEGARA configuration, data can be taken in different ways to reduce the overheads, get sky measurements, cover gaps in the exposure frames, facilitate the reduction process, or improve the quality of the obtained calibrations. We will refer to these ways of obtaining data in order to fit some specific observational requirements as "observing strategies".

Besides, MEGARA offers two general scientific OMs: exposing only with the LCB IFU mode ("LCB IFU scientific observation") and with the RPs ("Fiber MOS scientific observation") [R.15]. Each OM has its own general Observing Template (OT), which consists on a series of orders and parameters that are executed by the Sequencer to stablish the adequate configuration of the telescope, instrument, and auxiliary systems and to take a frame in the chosen OM.

Sometimes, it is useful to make specific realizations of a given general OT to implement a given observing strategy and use it during several observing runs. These specific implementations of one of the general OTs give place to other secondary OMs. Therefore, each OM has its own general OT and, in some cases, additional associated OTs for implementing specific observing strategies.

3.11. Operation Modes

From [R.16], an operation or observing mode (OM) is a data taking activity or data taking preparation activity with the telescope, instrument (in this case, MEGARA), and control system at certain established configurations, which are intrinsically associated to this OM.

The OMs that are required for the MEGARA control system in order to carry out observations with MEGARA include calibration, auxiliary, and scientific templates [R.15]. The MEGARA ETC implements the characteristics of the basic scientific OMs offered by MEGARA at each status of the project to estimate SNRs and exposure times.

3.12. Point spread function

The PSF is the flux distribution figure generated by the atmosphere+telescope+instrument system on the detector plane from a point-like signal.

3.13. Pseudo-slit

The MEGARA spectrograph has three interchangeable pseudo-slits, which can accommodate up to 650 fibers placed simulating a long slit of 119 mm length in each of them. Although the conceptual design allowed a total of ~700 fibers, a realistic design of the pseudo-slit suggests a maximum number of fibers of ~650. In MEGARA, a mechanism exchanges the pseudo-slit in place for the LCB IFU and MOS modes respectively. The pseudo-slit of the LCB IFU contains the fibers coming from 8 fixed bundles at the edges of the MOS field (i.e., 56 fibers) to facilitate the simultaneous acquisition of the sky spectrum with the LCB IFU [R.51].

3.14. Quantum efficiency

Quantum efficiency (QE) is the percentage of photons to be received by the detector that will produce an electron-hole pair. The MEGARA detector is a CCD231-84 (AR layer Astro Mult-2) [R.52].

3.15. Raw Data

Data as are retrieved from the detector, without any reduction.

3.16. Roboctic Positioner

The robotic positioner refers to each individual mechanical device of the Fiber MOS that is dedicated to put the fiber mini-bundle (which is composed by 7 fibers) at any position of the corresponding patrol area. The reference position for each positioner is the center of the central fiber of the 7-fiber mini-bundle.

The positioning of the fiber optical bundle is performed by combining the interpolation of two rotations. The interpolation between rotation 1 (R1) and rotation 2 (R2) allows covering the area assigned to each positioner.

3.17. Row stacked spectra

Row stacked spectra format (or RSS format) consists on a 2D FITS image in which the X-axis corresponds to the dispersion axis, and the other one corresponds to a given spatial ordering of the spectra determined by a position table [R.16, R.17]. Therefore, each RSS FITS file has an associated position table, which indicates the spaxel that corresponds to the Nth spectrum found in the Y-axis of the RSS FITS. In all the UML diagrams describing the MEGARA ETC and

Simulator, the classes associated to RSS have a coordinate file associated to them.

Note that the spectra in a RSS frame correspond to the spectra of each spaxel. They are obtained by collapsing the spectra in the spatial direction of the CCD frame either as an aperture or in an optimized way to reduce cross-talk. In MEGARA, each fiber is projected onto ~4 pixels in the spatial direction of the detector in raw data in all configurations by design (we will call them CCD frames). So, we will distinguish between RSS frames and CCD frames format henceforth.

The number of spectra in the RSS frames is equal to the number of fibers placed on the pseudo-slit that is being used (623 for the LCB and 644 for the MOS mode).

The MEGARA ETC estimates global SNR per spaxel (i.e., integrated for all wavelengths in the corresponding expected ideal spectrum of the spaxel), as well as SNR in several rings of spaxels given that when the consider FWHM in the sky the light of a point source is distributed in more than one spaxel, according to the simulations of flux homogeneity and distribution performed for the instrument [R.49].

3.18. Readout noise

The ReadOut Noise (RON) is the noise of a pixel in an image coming from the amplifier electronics attached to the CCD. It is included whenever the CCD is read. For MEGARA, it is ~2.8 electrons per pixel [R.51].

3.19. Spatial resolution

See §§3.8 and 3.20.

3.20. Spaxel

Minimum resolution element on the sky resolved by the different modes of MEGARA. The MEGARA spaxels are hexagonal shaped and have sizes of 0.62 arcsec for the LCB and MOS [R51]. These sizes correspond to the diameter of the circle on which the hexagonal spaxel is inscribed (see Figure 1).

3.21. Voxel

Minimum spectral and spatial resolution element in the detector plane of MEGARA for a given single wavelength. This corresponds to the projection of a single fiber at a given single wavelength onto the detector. This is ~4 pixels (3.6 pixels FWHM for LCB and MOS) both along the spatial and spectral (for a single wavelength) directions. The size of this projection might change slightly as a function of wavelength (λ-direction or X axis on the detector) and position of the fiber in the pseudo-slit (spatial-direction or Y axis on the detector). For most purposes, throughout this document we will adopt an average-sized region of ~4x4 detector pixels in both directions as the MEGARA voxel (see Figure 2).

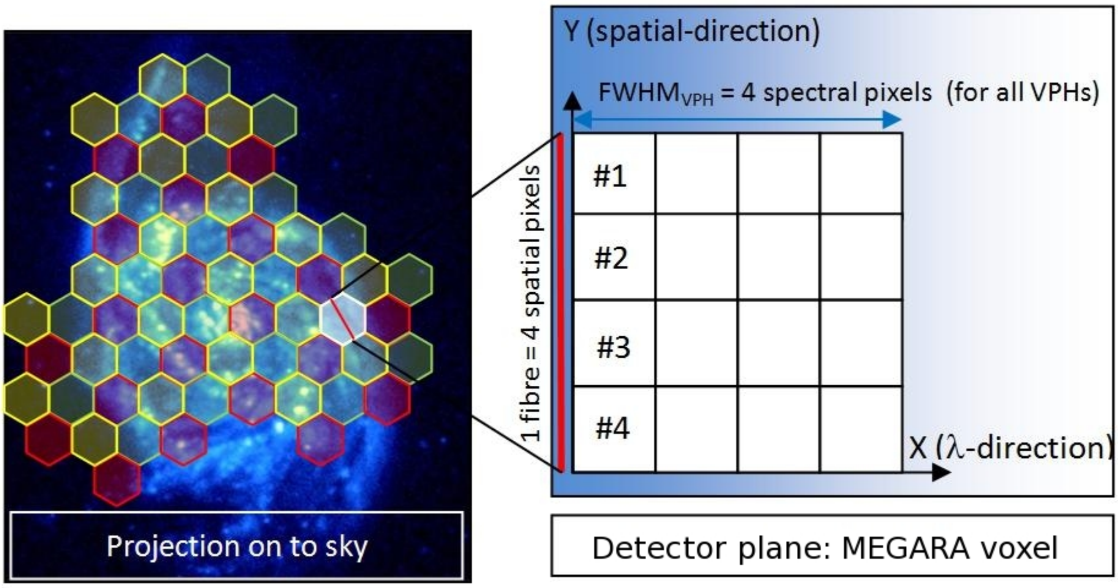

Figure 2: *MEGARA spaxel & voxel. The left panel shows a conceptual representation of the IFU configuration of MEGARA with different hexagonally shaped spaxels in different colors. The right panel shows a schematic projection on the detector of the light coming from the fiber whose corresponding spaxel is marked in white in the left panel.*

3.22. Spectral resolution

See §3.8 and §3.21.

3.23. VPH

Volume-Phase Holographic (VPH) gratings diffract light by refractive index modulations within a thin layer of material sandwiched between two glass substrates. Light is diffracted at angles corresponding to the classical grating equation as a function of the incident angle and the frequency of the index modulation at the surface of the grating. The diffraction efficiency, however, is a strong function of the relationship between the angle of incidence and angle of diffraction with respect to the fringes formed by the refractive index modulations within the volume of the grating. If these relationships satisfy the Bragg condition, which also depends on the depth of the grating volume and on the intensity of the grating fringes, then high peak diffraction efficiencies, approaching 100%, are possible [R.19]. For more information, consult [R.20].

The definitive list of MEGARA VPHs and their basic properties (dispersion, spectral range, and spectral resolution) is provided in Table 1 [R.51].

VPH Name	Setup	R_{FWHM}	λ_1-λ_2 Å	λc Å	$\Delta\lambda_{FWHM}$ (@ λc) Å	Δv_{FWHM} km/s	line res Å/pix
VPH405-LR	LR-U	6028	3653 – 4386	4051	0.672	50	0.17
VPH480-LR	LR-B	6059	4332 – 5196	4800	0.792	49	0.20
VPH570-LR	LR-V	6080	5143 – 6164	5695	0.937	49	0.23
VPH675-LR	LR-R	6099	6094 – 7300	6747	1.106	49	0.28
VPH799-LR	LR-I	6110	7220 – 8646	7991	1.308	49	0.33
VPH890-LR	LR-Z	6117	8043 - 9630	8900	1.455	49	0.36
VPH410-MR	MR-U	12602	3917 - 4277	4104	0.326	24	0.08
VPH443-MR	MR-UB	12370	4225 – 4621	4431	0.358	24	0.09
VPH481-MR	MR-B	12178	4586 – 5024	4814	0.395	25	0.10
VPH521-MR	MR-G	12035	4963 – 5443	5213	0.433	25	0.11
VPH567-MR	MR-V	11916	5393 – 5919	5667	0.476	25	0.11
VPH617-MR	MR-VR	11825	5869 – 6447	6170	0.522	25	0.13
VPH656-MR	MR-R	11768	6241 – 6859	6563	0.558	25	0.14
VPH712-MR	MR-RI	11707	6764 – 7437	7115	0.608	26	0.15
VPH777-MR	MR-I	11654	7382 – 8120	7767	0.666	26	0.17
VPH926-MR	MR-Z	11638	8800 - 9686	9262	0.796	26	0.20
VPH665-HR	HR-R	18700	6445 - 6837	6646	0.355	16	0.09
VPH863-HR	HR-I	18701	8372 - 8882	8634	0.462	16	0.12

Table 1: *MEGARA VPHs characteristics for the LCB IFU and MOS modes.*

4. SCOPE

This document presents the Users Guide of the MEGARA ETC, which is a software tool included in the MOPSS. It includes user documentation detailing relevant information for users, in particular, the physical models, assumptions, and equations used in the tool.

The UCM group of Extragalactic Astrophysics and Astronomical Instrumentation (GUAIX) is responsible of developing this tool. A first prototype of this tool was presented at the Preliminary Design Phase of the instrument. It has been updated and improved for the Critical

Design Review of MEGARA, accounting for the changes performed to its design and taking into account the results of the AIV phase.

The MEGARA ETC is a tool to simulate the SNRs or limiting fluxes (and magnitudes) that would be obtained for a given exposure time and GTC+MEGARA setup, in both continuum and line emission. A set of input parameters defining the continuum flux distribution and/or the wavelength and FWHM of the line of the input source must be provided, as well as those defining the instrument configuration, atmospheric conditions of the run, and some characteristic of the observational strategy.

5. THE ONLINE VERSION

The latest and most current version of the MEGARA ETC (v1.0.0, June 2017) is now accessible online, via any web browser, and from any platform. It does not require any special environment, nor installation. The computation is done on the server where the ETC code is and does not require any local resources to display a webpage. While no installation is necessary, it should be noted that an internet connection is needed for its usage.

The core code of this online version is the similar to the one for the legacy offline version (v0.4.1). It is written in Python-2.7 and uses the libraries numpy[1] and scipy[2]. We make use of the free and open-source Django Python Web Framework[3] (v.1.10). It is one of the most advanced and stable web framework available today, and allows us to set up the required architecture for outputting results generated by Python codes to be displayed in a web browser. Django basically brings the power of Python to the web. For example, we can now easily generate graphical outputs using modules such as matplotlib[4] that produces figures of publication quality. Another advantage of using this framework is for its scalability. New functionalities can be added more easily than the previous standalone versions. Without going in too much details about Django, it is helping to summarize the following:

- A python code on the server generates the input form fields on top of a HTML/CSS/JS template page, and sends the finalized HTML page (what the user sees).

- The POST method is used to send the user's inputs back to the server. Computations are done on the server, results are generated, and sent back to the HTML page.

It turns out that the user does not need to know any of this since the user will only interact with the ETC via a common HTML form.

The current ETC version has been tested on different platforms (web browsers), such as Mac OS X (Chrome, Safari, Firefox), iPad (Safari), iPhone (Safari), and Linux (Fedora, Ubuntu, CentOS) (Firefox), however, we strongly recommend to use the latest versions of Chrome or Firefox. We did not test the ETC on Internet Explorer.

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[1] Webpage: http://numpy.scipy.org/

[2] Webpage: http://www.scipy.org/

[3] Webpage: https://www.djangoproject.com/

[4] Webpage: http://matplotlib.org/

6. PHYSICAL CONSIDERATIONS FOR THE MEGARA ETC

The MEGARA ETC considers the transmission curves measured for the atmosphere + telescope + instrument complete system. We comment on them below. We also comment on the source flux spectra considered for the continuum distribution, on how they are normalized to a given input magnitude or flux in a certain photometric band, and on the sky emission spectra assumed in the ETC, according to the night conditions.

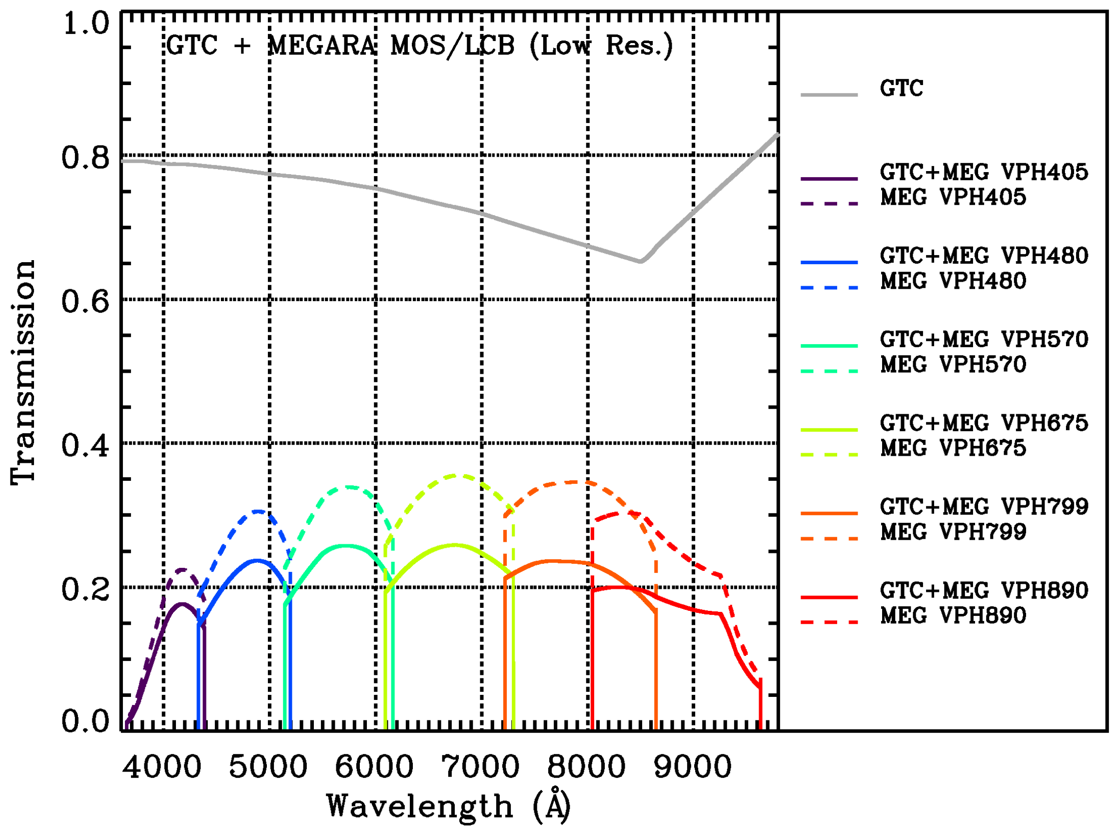
6.1. Transmission of the telescope

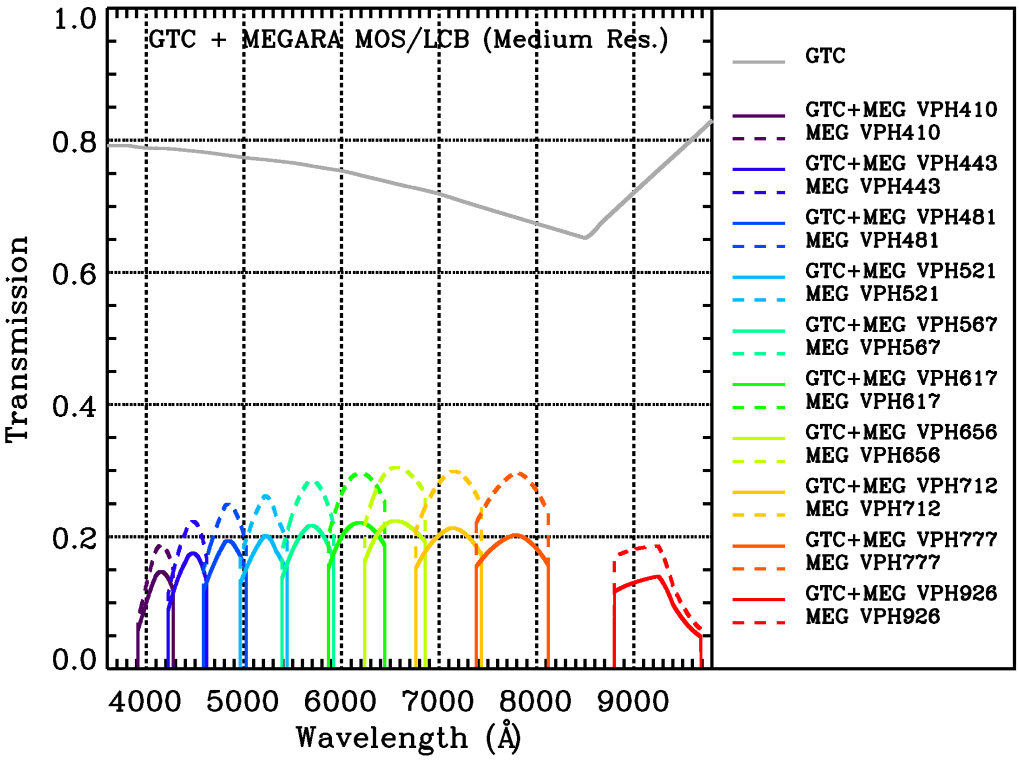
The transmission curve of the telescope in *Figure 3* (grey line) accounts for the transmission of the three aluminum-coated mirrors of GTC.

6.2. Transmission of the instrument

In *Figure 3*, we show the transmission curves of MEGARA in the LCB/MOS modes, for low, medium, and high spectral resolution (LR, MR, and HR), as a function of the wavelength [R.52].

The transmission curves in dashed lines include the transmission of the Folded-Cassegrain subsystem + the spectrograph + the grating subsystem in LR, MR, and HR, considering the VPH that covers optimally each wavelength region in each spectral resolution. The transmission curves shown below include the GTC transmission at the top (solid line).





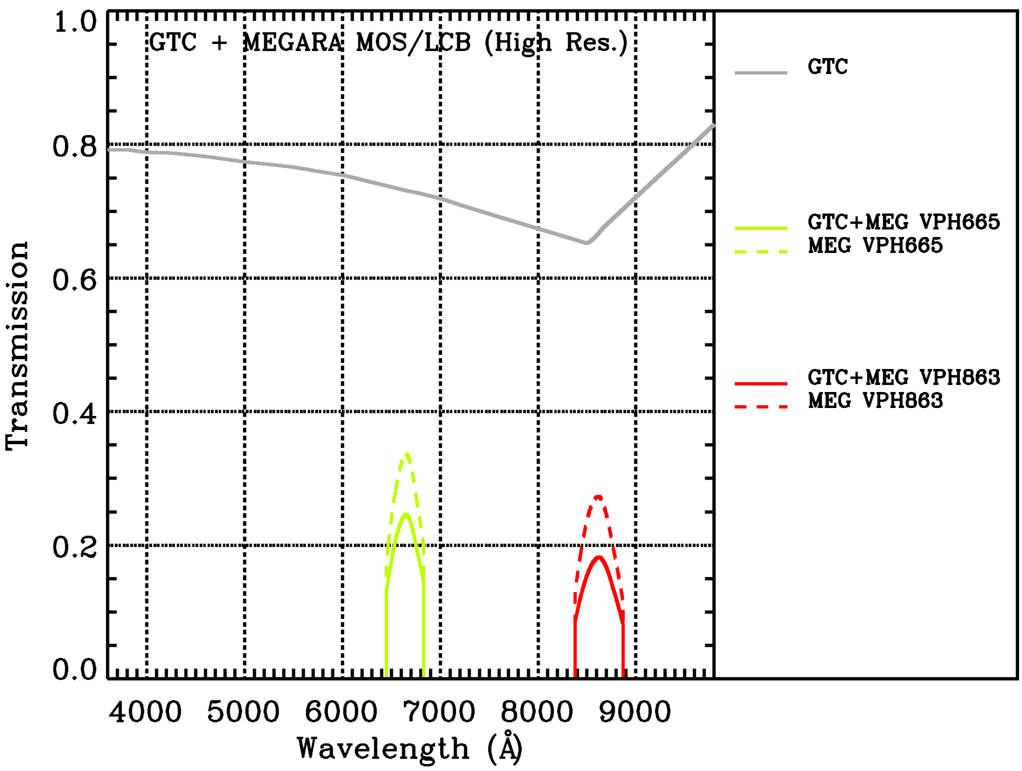


Figure 3: *Transmission curves of GTC+MEGARA (continuum lines) and MEGARA (dashed lines) in the LCB/MOS modes, for low, medium, and high spectral resolution as a function of the wavelength.*

6.2.1. Folded-Cassegrain Subsystem

The curve of the Folded-Cassegrain subsystem includes the effects in transmission efficiency of the field lens + microlens + pupil system (for LCB/MOS modes) + Focal Ratio Degradation (FRD) + fiber transmission (considering a length of the fiber link of 40 m) + the fiber exit [R.52]. All these curves are represented in Figure 4.

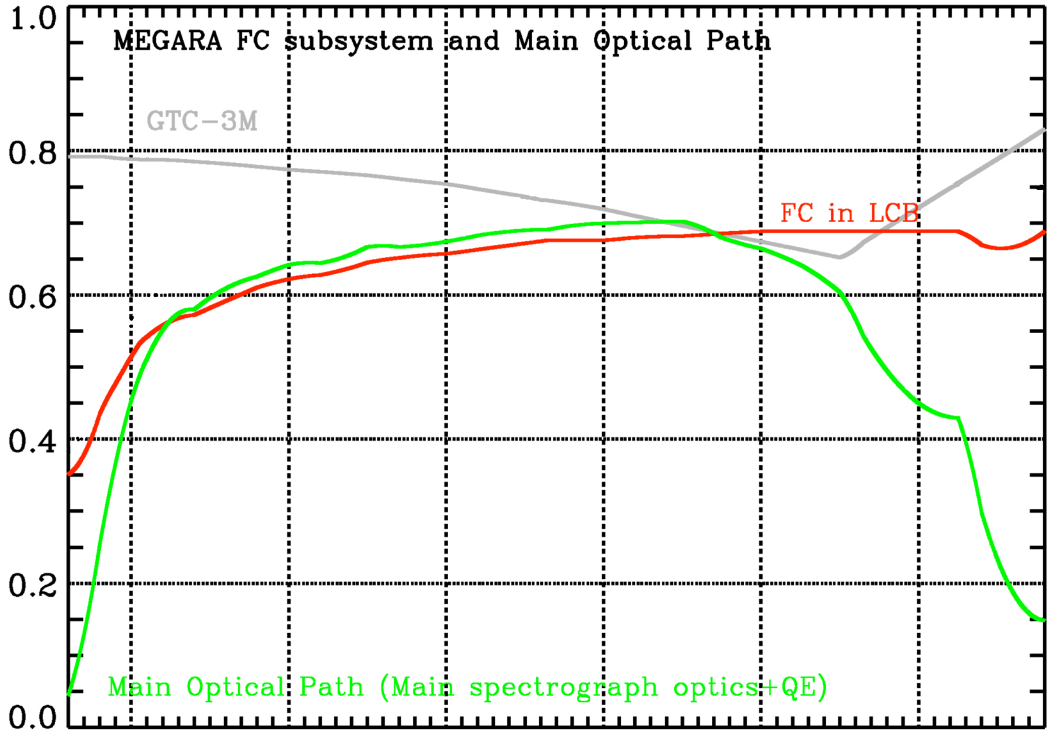


Figure 4 *: Transmission curves of the MEGARA Folded-Cassegrain subsystem and of the Spectrograph subsystem including the main optics of the spectrograph and the detector QE (but no grating).*

The attenuation power of the MEGARA fibers, α(λ), is plotted in *Figure 5*. The final attenuation of a fiber depends on its length (L_{fiber}), according to:

$$A_{\rm fibre}(\lambda) = \alpha(\lambda) \cdot L_{\rm fibre} \ . \ (2)$$

If α(λ) is provided in dB/km (as in *Figure 5*), the length of the fiber must be provided in km. Finally, the total transmission of the fiber can be estimated as follows:

$$T_{\rm fibre}(\lambda) = 10^{[A_{\rm fibre}(\lambda)/(-10)]} \ . \ (3)$$

An average fiber length of L_{fiber} = 40 m has been adopted for MEGARA, obtaining the fiber transmission curve represented in Figure 4.

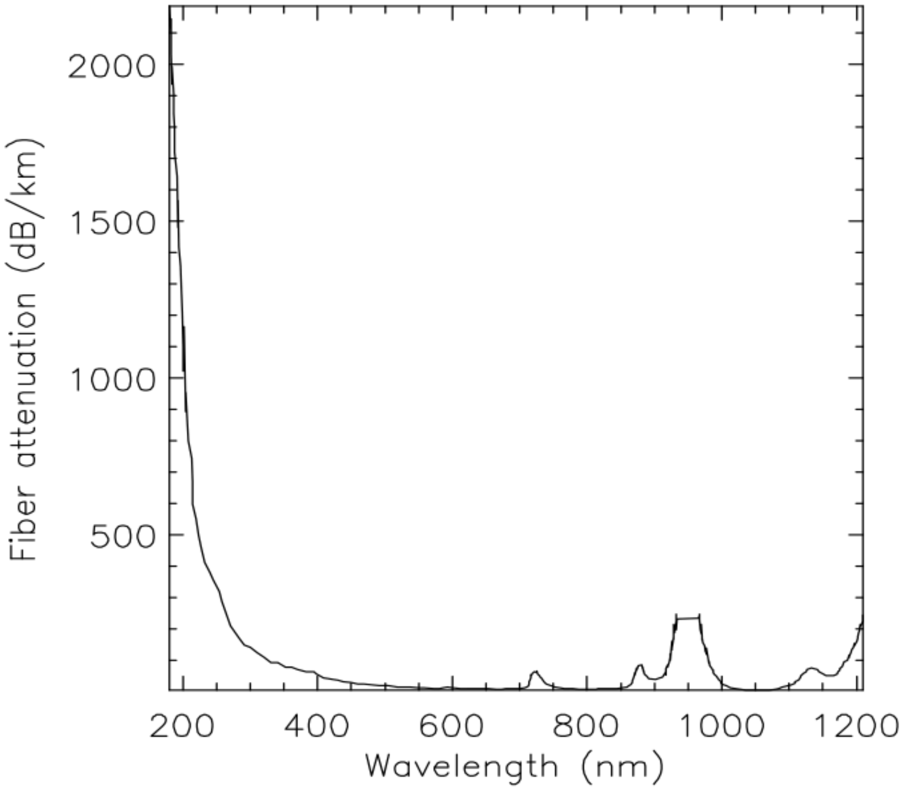


Figure 5: *Attenuation power of MEGARA fibers.*

6.2.2. Spectrograph Subsystem

The transmission curve of the spectrograph accounts for the transmission of the main spectrograph optics (entrance window + lenses + mirrors) + the detector QE [R.52]. See Figure 4.

The detector is an E2V CCD231-84-0-E74 device [R.51]. This CCD measures 4096 x 4112 x 15µm pixels and has four outputs. There are several variants of this device but MEGARA uses the Deep-Depletion Silicon version with the Astro Multi-2 AR coating as being the one best suited for the demands of MEGARA. The CCD has excellent QE across almost the whole visible spectrum.

The ETC requires the read-out noise (RON) in electron per pixel (< 3 electrons, see §3.18) and the dark current noise (DC) in electron per pixel and per second. The last one is negligible for MEGARA detector (0.02 electrons/pixel/hour) [R.52].

6.2.3. Grating Subsystem

The grating subsystem accounts for the transmission of the different VPHs + the efficiency of associated elements (including the order sorting filter to be used in the VPHs transmitting in the red part of the optical spectrum). The VPHs transmission curves are plotted in Figure 6, including the efficiency of adjacent elements in LR, MR, and HR (as the prism in the MR and HR gratings and the vigneting due to the HR prism [R.52]).

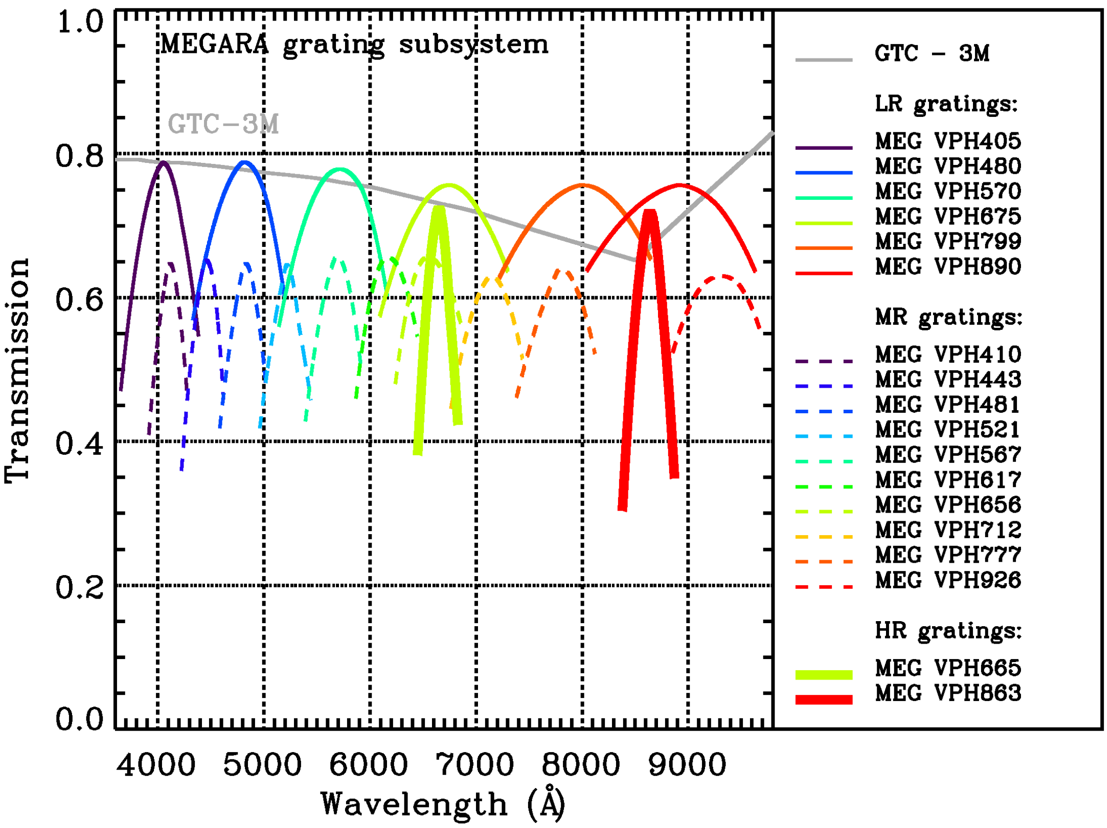


Figure 6: *Transmission curves of the different MEGARA grating subsystem, including the efficiency of associated elements and order sorting filters when needed.*

6.3. Source flux spectra

In the ETC, the input total Vega magnitude of the source continuum in any given input photometric band is converted into total flux in that band (F_i), according to [R.23]:

$$F_i = F_{0,i} \cdot 10^{-(m_i - m_{0,i})/2.5}, \quad (4)$$

where $F_{0,i}$ and $m_{0,i}$ are the Vega flux and magnitudes in that band, and m_i is the target magnitude in that band. The magnitudes and fluxes of Vega in different bands are provided in *Table 2*, as well as the central wavelengths $\lambda_{0,i}$ and bandwidths $\Delta\lambda_{0,i}$ of the considered Johnson-Bessel bands.

Band	Vega magnitude m_0	Vega flux @λ_0 $F(\lambda_0)$ (erg/s/cm2/Å)	Eff. wavelength λ_0 (Å)	Band-width $\Delta\lambda_0$ (Å)
U Johnson-Bessel	0.030	4.22E-9	3657.5	577
B Johnson-Bessel	0.035	6.20E-9	4334.5	975
V Johnson-Bessel	0.035	3.55E-9	5374.0	846
R Johnson-Bessel	0.075	1.795E-9	6272.5	1273
I Johnson-Bessel	0.095	8.60E-9	8722.0	2980

Table 2: *Vega magnitudes and fluxes in certain Johnson-Bessel photometric bands [R.31]. Central wavelengths and bandwidths of the Johnson-Bessel photometric filters [R.32-R.34].*

The flux computed above corresponds to the flux at the effective wavelength of the corresponding band (see column 4 of *Table 2*). Note that this flux is given per Å, by definition.

The input source spectrum template $F_{template}(\lambda)$ selected by the user is normalized in order to have a flux per Å at the effective wavelength of the input continuum band equal to unity:

$$\mathcal{F}_{\rm norm}(\lambda) = \frac{\mathcal{F}_{\rm template}(\lambda)}{\int_{\lambda_{0,\rm i}-0.5\mathring{A}}^{\lambda_{0,\rm i}+0.5\mathring{A}} \mathcal{F}_{\rm template}(\lambda)\cdot T_i(\lambda)\cdot d\lambda} \quad , (5)$$

where $T_i(\lambda)$ represents the transmission of the considered band (see *Figure 7*). The normalized spectrum is then scaled to ensure that the flux per Å in the input continuum band at the effective wavelength equals to the input flux per Å provided by the user in that band, as follows:

$$\mathcal{F}_{\rm scaled}(\lambda) = F(\lambda_{0,\rm i})\cdot\mathcal{F}_{\rm norm}(\lambda) \quad , (6)$$

where $F_{norm}(\lambda)$ is obtained through eq. 5. Notice that $F_{scaled}(\lambda)$ at the effective wavelength of the input continuum band i is the one inserted by the user as input:

$$\int_{\lambda_{0,\rm i}-0.5\mathring{A}}^{\lambda_{0,\rm i}+0.5\mathring{A}} \mathcal{F}_{\rm scaled}(\lambda)\cdot T_i(\lambda)\cdot d\lambda = F(\lambda_{0,\rm i}) \quad . (7)$$

$F_{scaled}(\lambda)$ represents the energy flux spectrum of the input source, as set by the user's inputs. If the input source is punctual (as in some cases of the ETC if a stellar spectrum is selected as input), this energy flux spectrum corresponds to the emission in the whole source area (i.e., it is given in erg/s/cm^2/Å); whereas if the input source is extended (rest of cases in the ETC), it corresponds to the energy flux spectrum of the source per arcsec^2 (as the input continuum magnitude or flux provided by the user is requested to be given per arcsec^2, see §7.2).

The total continuum flux of the input source can be easily computed at any other photometric band j, as follows:

$$F_{\rm j} = \int_{\lambda_{j,0}-\Delta\lambda_j/2}^{\lambda_{j,0}+\Delta\lambda_j/2} \mathcal{F}_{\rm scaled}(\lambda)\cdot T_j(\lambda)\cdot d\lambda \quad . (8)$$

$T_j(\lambda)$, $\lambda_{j,0}$, and $\Delta\lambda_j$ being the transmission curve, central wavelength, and the bandwidth of the photometric band *j*.

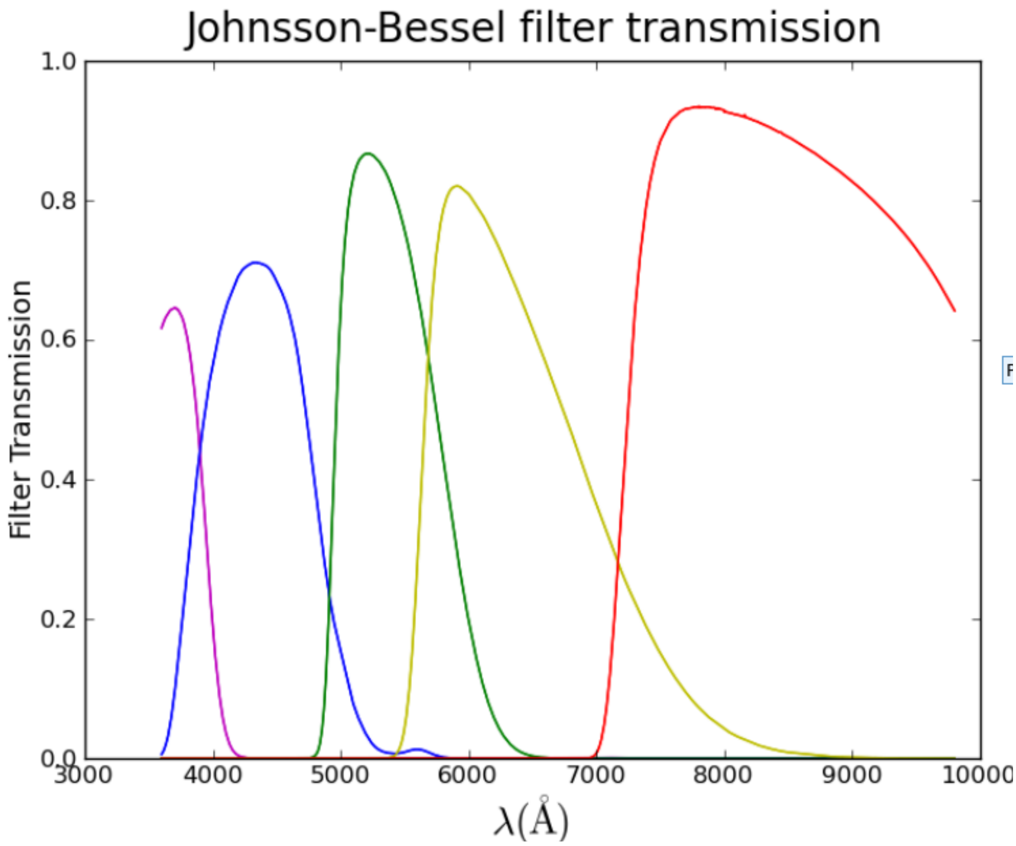


Figure 7: *Transmission curves of the Johnson-Bessel photometric bands [R.35]. All transmission curves of MEGARA ETC are provided in steps of 0.1Å, obtained through linear interpolation.*

The template spectra of the MEGARA ETC ($F_{template}(\lambda)$ in Eq. 5 above) are the same as those in the ETC of GTC/Elmer instrument, kindly made available by M. García-Vargas. It consists of a set of standard spectra of stellar, galactic, and extra-galactic objects. They are plotted in Figures 8 and 9.

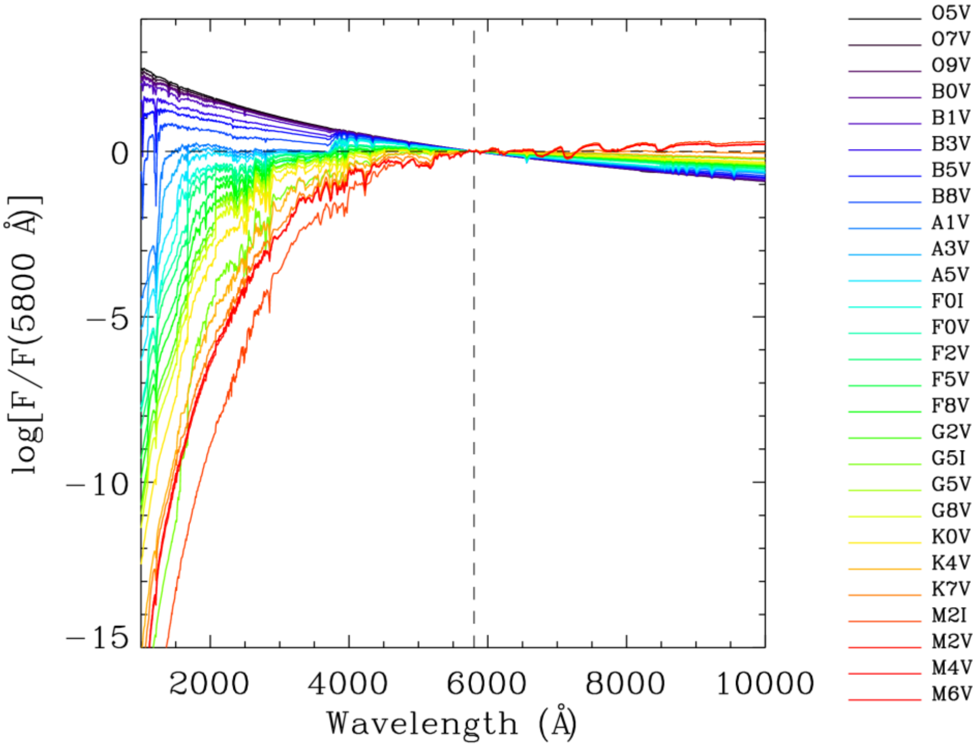


Figure 8: *Input spectra of typical stellar types available in the MEGARA ETC.*

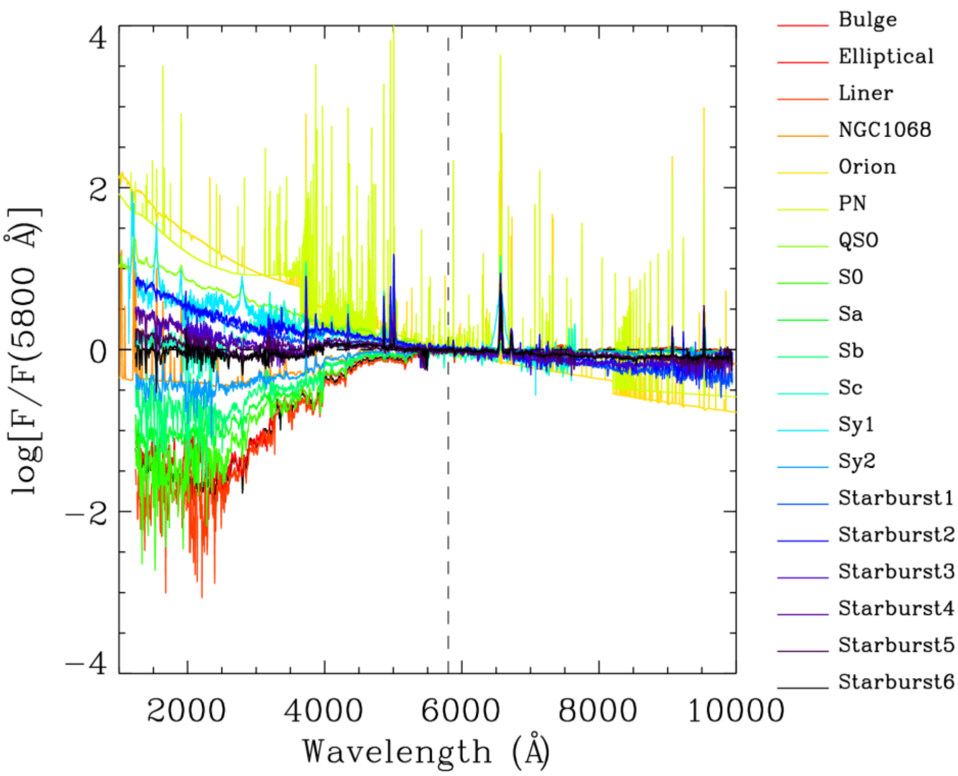


Figure 9*: Input spectra of typical Galactic and Extragalactic targets available in the MEGARA ETC.*

6.4. Sky background emission

The present version assumes that the input sky spectrum in the optical range is uniform. The sky emission magnitude is initially set in the photometric band that presents the widest overlapping range with the wavelength range of the user-selected input VPH (see *Table 1*). This magnitude (provided by arcsec^2, consult *Table 2*) is converted to flux per Å using Eq. 4. The sky emission in any band can be then estimated with Eq. 8. As the sky emission in El Roque de los Muchachos Observatory Observatory has found to be quite similar to that of Mauna Kea [R.36], a sky spectrum of Mauna Kea will be used for GTC/MEGARA.

6.5. Atmospheric transmission and extinction

The atmospheric extinction on La Palma is discussed in detail in [R.53]. It is possible to separate the extinction into two components: one due to Rayleigh scattering by air molecules and absorption by ozone (which is wavelenght-dependent), and another due to dust (aerosol) scattering (which in independent on wavelength).

The wavelength-dependent component measures the atmospheric transmission in a dust-free atmosphere. This component at El Roque de los Muchachos Observatory is quite similar to that of the Mauna Kea observatory in the optical range, although slightly lower [R.36, R.37]. In *Table 3*, we show a comparison of the atmospheric transmission of both sites. The atmospheric transmission curve of Mauna Kea in the optical range is plotted in *Figure 10* (red line).

The (dust-free) atmospheric transmission curve available for Mauna Kea does not account for a series of atmospheric absorption features usually present in observing sites, as those present in the atmospheric transmission curve of the AAO site (see blue line in *Figure 10*). In order to account for the global transmission curve of La Palma and to also include these absorption features, we have combined both curves to obtain a combined transmission curve representative of the atmospheric transmission in La Palma for the MEGARA ETC (black line in *Figure 10*).

Dust scattering at the Roque de los Muchachos observatory does not depend strongly on wavelength over the optical range [R.53]. Therefore, it just includes a constant to the wavelength-dependent term of the atmospheric extinction (in units of mag per airmass). The extinction due to dust scattering varies from night to night, but is usually less than a few tenths of a magnitude per unit airmass. We do not account for the atmospheric extinction by dust (the wavelength-independent term) in the MEGARA ETC.

Wavelength (Å)	Atm. transmission (%) @La Palma	Atm. transmission (%) @Mauna Kea
4000	72	79
4500	80	85
5000	84	89

Table 3: *Comparison of the atmospheric transmission of La Palma and Mauna Kea observatories [R.36, R.37].*

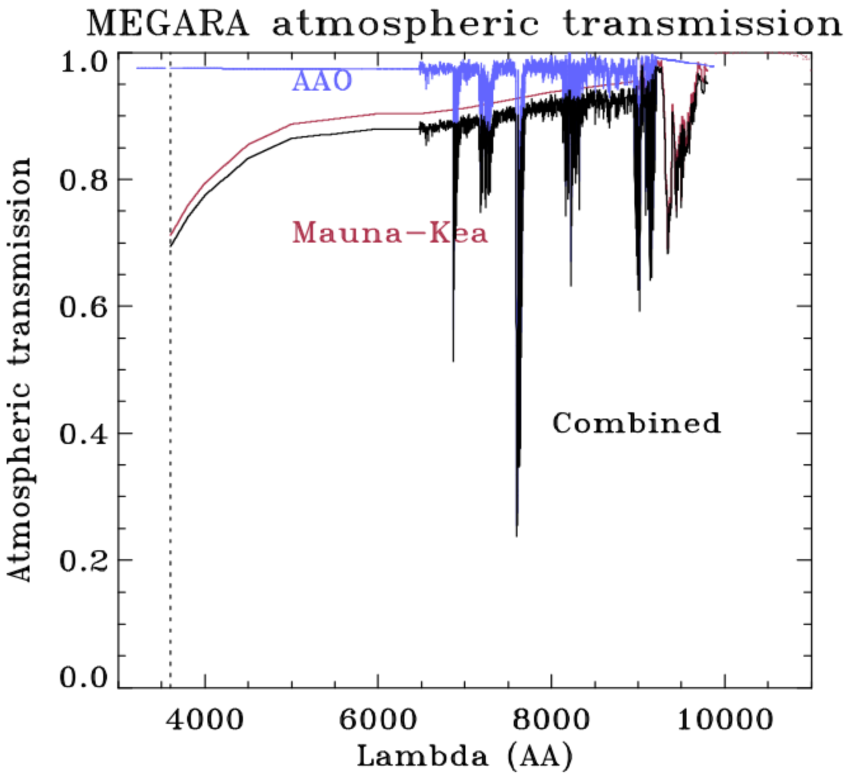


Figure 10: *Transmission curve of the atmosphere used in MEGARA ETC.* ***Blue curve****: Empirical atmospheric transmission curve from the Anglo-Australian Observatory (AAO), used in the OSIRIS ETC [R.38].* ***Red curve****: Atmospheric transmission curve from Mauna-Kea observatory [R.36].* ***Black curve****: Combined AAO-Mauna-Kea atmospheric transmission curve, finally used in MEGARA ETC.*

7. THE MEGARA ONLINE EXPOSURE TIME CALCULATOR

Previous versions of the MEGARA ETC provided estimates of the SNRs on continuum and line flux distributions that would be obtained for a given exposure time, GTC+MEGARA setup, and certain observing conditions, according to the current MEGARA design [R.51]. The latest version also estimates the required exposure time for achieving a given SNR at the central wavelength of a VPH in the case of the continuum or at a given wavelength in the case of an emission line.

The current version can be used to derive the computations above just using an iterative method until the limiting magnitude for a given exposure time and SNR is obtained in the central wavelength of the VPH for continuum or at the line. Now, the tool provides the SNR at the central wavelength of the VPH when considering a voxel in continuum estimates.

7.1. Graphical User Interface

This version of the MEGARA ETC allows the user to select the input parameters in a web form via a single web browser page. Output estimates of the SNRs are shown in the bottom half of the page. These outputs can be saved into a text file. As of this version, graphical outputs are also generated, bringing the need to save the graphical results as well. One of the advantages of having the ETC in a web browser is that saving graphics from a browser has nowaday become an easy task with most common browsers.

In Figure 11, we show a snapshot of the graphical user interface (GUI) of the online version of the ETC tool (v1.0.0, June 2017).

Once the user has selected a certain combination of input parameters, he/she can start the SNR (or exposure time) estimate by clicking the **“Submit”** button and choosing the corresponding option. Warning messages are shown if issues are found in the input parameters. The input parameters are shown again in the output, and the resulting SNRs will appear in the "Continuum output" and "Line output" SNR/t_{exp} tables in the section at the bottom half of the same page, for the selected continuum and the line input parameters respectively.

Results can be opened in a new window and saved as a plain text file (.txt) by clicking on the **“Store Results”** button and using the save feature of the browser. The text file will be saved, in general, in the browser’s Download directory.

The input fields can be reset to its default values by clicking on the **“Reset”** button. As of version 0.4.5, we use cookies to store the input form values. The current cookies can be viewed by clicking on the **“Show Cookies”** button. The cookies are kept for 365 days, and are automatically erased beyond that. They are also erased when the **“Reset”** button is pressed.

For more information, the user can click on the **“Help”** button of the MEGARA ETC. This will show a quick guide and explanations of the input fields and output results. A more detailed manual (this document) is available by clicking the **“Manual”** button. A brief explanation of each field is also available by clicking on the input field name itself. Clicking a question mark **“?”** on the right side of a field gives additional information.

To quit the ETC, just close the browser window.

The tool has several warnings implemented to avoid incorrect input or unreallistic input physical values. When the **"Submit"** button is pressed, errors messages and input suggestions are shown in the lower-half of the page to inform the user of a problem.

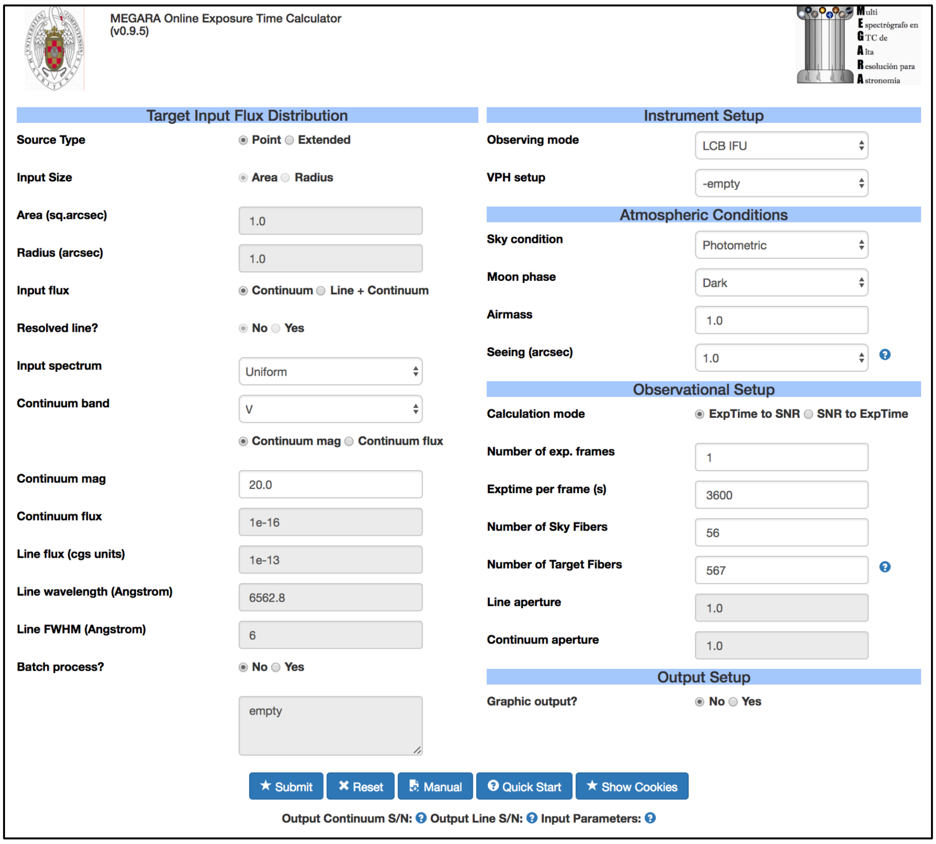


Figure 11: *GUI of the online version of MEGARA ETC (v1.0.0, June 2017). The form may appear slightly different from one browser to another and from one operating system to another.*

7.2. Input parameters

The GUI of the ETC allows the user to fix a set of input parameters describing the characteristics of the observation they are interested in simulating, specifically those concerning to:

- the input target (geometry, spectrum, magnitude of continuum/line, FWHM and wavelength of line),
- the observing night (sky condition, moon phase, seeing, airmass),
- the observing run characteristics (number of frames, exposure time per frame, number of sky mini-bundles used, spectral apertures to get continuum and line fluxes, SNR),
- the instrumental setup (VPH of use, quantum efficiency of the CCD+coating of use).

The following parameters are fixed internally in the software and concern to the GTC+MEGARA specifications:

- the telescope (mirrors transmission, collecting area, see §6.2),
- the transmission of MEGARA (Folded-Cassegrain + spectrograph + grating transmission, see §6.2),

- detector plate scale.

The input parameters that can be modified by the user are detailed below.

7.2.1. User required outputs

The user must select the kind of output provided by the ETC. Each kind of output requires certain different input parameters. For a given input instrumental setup and atmospheric conditions, the user can request:

1. The SNR expected by the ETC on a given input source for a given input exposure time, both on a continuum or in a line flux distribution.
2. The SNR vs. wavelength expected by the ETC on a given input source for a given input exposure time, in continuum flux distributions.
3. The exposure time required to achieve a given SNR at the central wavelength of the selected VPH for the input source in continuum or at a given emission line.
4. The limiting magnitude or flux of a continuum or line flux distributions for a fixed SNR achieved for a given exposure time (under development).

The computations available in the current online version are the first three. However, computation 4 can already be estimated by iteratively changing the input flux until the desired SNR and exposure time is reached as output for the resolution element that the user is considering (detector pixel, voxel, spaxel, or total source).

7.2.2. Target Input Flux Distribution

This set of parameters is intended to describe the flux distribution of the source to be observed.

1. **Target type:** It indicates if the source is unresolved (point source) or extended. If a point source is chosen, the target object is assumed to be an emitter with negligible intrinsic angular size. This can be selected for objects with an angular radius much smaller than the seeing-disk size. If extended source is chosen, the target object is assumed to have a uniform intensity across its whole projected area. If 'Source Type = Extended', then the input parameter 'Size' becomes mandatory.
2. **Target projected size (Area or Radius):** For extended sources, apparent projected area of source in arcsec^2 (A_{obj}). Circular shape is assumed for the source. This parameter is available only if the 'Source Type = Extended' option is set. The area can directly be given in arcsec^2, or as a radius which is then squared and multiplied by pi, depending on the selected 'Input Size' radio button.
3. **Input target flux:** Type of data inserted to get the SNR. If 'Input flux = Continuum', only input data necessary to define the continuum of the source are required for computation. If 'Input flux = Line + Continuum', the following input parameters become mandatory too: 'Resolved line', 'Line flux', 'Line wavelength', 'Line aperture', and 'Continuum aperture'.

4. **Resolved line:** This parameter indicates if the line can be resolved or not, and it is relevant only if 'Input flux = Line + Continuum'. If the line is resolved, the user must insert the line FWHM. Otherwise, the FWHM of the line is determined in the basis of the VPH selected.

5. **Input spectrum:** The target model can be defined by the target spectral type. It uses a template spectrum, which is scaled to the magnitude and filter provided. The spectral type is used to make the color correction and continuum background subtraction. We remark that no line diagnostics are derived from an input spectrum template, only continuum ones. When 'Input flux = Line + Continuum'

6. **Continuum band:** Photometric band in which the input continuum magnitude or flux is provided. The input template spectrum is scaled to the input magnitude in this band.

7. **Continuum magnitude:** For point sources, Vega apparent magnitude of the source continuum in the selected continuum band. For extended sources, the magnitude must be provided per arcsec^2 in the selected band. Only available if 'Continuum flux' option is not set.

   Note: This option can be filled if the output requested by the user is an exposure time or a SNR to be determined over the continuum (§7.2.1). It cannot be filled if the users request the estimate of the limiting magnitude over a given continuum template to be achieved in a given exposure time and for a given SNR (§7.2.1). In the current tool, only SNR estimates are provided as outputs, so this option can be filled always, unless 'Continuum flux' option is set.

8. **Continuum flux:** For point sources, flux of source continuum in c.g.s. units (erg/s/cm^2/Å) in the selected continuum band. For extended sources, this flux is provided per arcsec^2. Only available if the 'Continuum Magnitude' option is not set.

   Note: In the current version, this input can be filled in any case, but in future versions of the tool this input shall be blocked if it requested as an output (§7.2.1).

9. **Line flux:** For point sources, flux of line in c.g.s. units (erg/s/cm^2). For extended sources, this flux must be provided per arcsec^2. This parameter is available only if the 'Input flux = Line + Continuum' option is set.

   Note: This input shall be blocked in future versions of the tool that may provide it as output (§7.2.1).

10. **Line wavelength:** Line wavelength in Å. This parameter is available only if the 'Input flux = Line + Continuum' option is set.

11. **Line FWHM:** Line FWHM in Å. If the line is not resolved, the nominal FWHM of the selected VPH at its central wavelength is assumed (consult Table 1). This parameter is available only if the 'Input flux = Line + Continuum' and 'Resolved line = yes' options are set.

12. **Batch process?**: Batch processing for a maximum of 500 targets is now possible (from version 1.0.0). This feature only works when the Target type (Source Type) is set to

"Point source". When "Yes" is selected, the user can input a list of objects in the text field below. A comma-separated format is required, with three input columns: (1) the target's name (can be anything), (2) the UBVRI filter in which the calculation should be applied (corresponds to "Continuum band" above), and (3) the target's Vega magnitude (corresponds to "Continuum magntidue" above). Lines containing the "# (sharp)" character are ignored. An example is given in its help window.

13. **SNR:** Signat-to-noise required. The output in this case will yield the exposure time needed to reach this SNR for the corresponding region in the detector (both along the spatial and spectral direction).

7.2.3. Instrumental setup

This set of parameters is intended to describe the instrument initial setup (basically, the VPH to be selected by the user).

1. **Observing mode:** There are two observing modes to MEGARA: the MOS mode and the LCB IFU mode. In MOS mode, the total number of fiber bundles is 92 (644 fibres), whereas in the LCB IFU mode, the number of dedicated fibres is 623 including the 8x7=56 sky fibres.

   In MEGARA, there will be several scientific OMs (see [R.15]). "IFU-only observation" includes LCB IFU observing mode, while the "Robotic positioners-only observation" includes the Fiber MOS scientific observing mode.

2. **VPH setup:** The characteristics of each spectral VPH setup are listed in *Table 1*. The wavelength of the input spectral line (in the case that the users require line diagnostics) must be located into the wavelength range of the selected VPH. A program warning is shown if this requirement is not fulfilled and no computation is performed.

7.2.4. Atmospheric conditions during the observing run

Depending on the atmospheric conditions during the data taking, the number of photons and the seeing FWHM of the observed source change. The ETC has these effects taken into account.

1. **Sky condition:** This option allows the user to choose from the following sky conditions: photometric/clear/spectroscopic. The sky condition affects the overall efficiency of the system and corresponds to the following changes: photometric is 100% (no change), clear is 69%, and spectroscopic is 39%.

2. **Moon phase:** The following options for the night brightness are available: dark/grey/bright. The sky magnitude at a dark night in La Palma at the zenith is initially set in the photometric band nearest to the user-selected VPH (consult Table 4). These values have been found to be independent of atmospheric extinction, and do not vary appreciably during the night, but with solar cycle, latitude and airmass [R.24]. In the present version, the sky spectrum is assumed to be uniform. In future versions, a typical atmospheric spectrum will be scaled to the selected magnitude [R.21]. The typical average extra brightness between a dark and grey or bright night is added, depending on the user-selected moon phase (consult Table 5), assuming that the difference of

emission between dark and bright or dark and grey does not depend on the optical band. The average emission due to zodiacal light, airglow, and starlight has been also considered [R.25].

3. **Airmass:** Airmass scales the number of photons from the sky background according to the following expression [R.26]:

$$S_{\rm sky}(X) = S_{\rm sky}(X=1)\cdot[-0.000278719X^3-0.0653841X^2+1.11979X-0.0552132] \quad . (9)$$

4. **Seeing:** FWHM of the seeing in arcsec. The value refers to the FWHM of the seeing disk in V band, at the requested airmass. Note that the variation of seeing with airmass X can be assumed to scale as follows [R.26]:

$$\mathrm{FWHM}_{\rm seeing}(X) = \mathrm{FWHM}_{\rm seeing}(X=1)\cdot X^{3/5} \quad . (10)$$

The above expression can be used to predict the expected seeing at different airmasses, which is some situations can be useful in the case the user needs to simulate observations performed at different telescope elevations. It is important to highlight that the ETC will always assume the user has properly introduced the expected seeing at the quoted airmass.

The seeing value at the selected airmass is written to the "Input parameters" output table each time the ETC is executed.

Band	Sky brightness (mag/arcsec^2)	γ (photons/s/m/arcsec^2/Å)
U	22.0	0.012
B	22.7	0.012
V	21.9	0.017
R	21.0	0.029
I	20.0	0.049

Table 4: *Near-zenith dark-of-moon broad-band sky brightness at La Palma for different bands. Values are taken from [R.24].*

Moon Phase[1]	Δmag (mag/arcsec^2)
Bright	3.1
Grey	1.5
Dark	0.5

[1]These values already account for zodiacal light, airglow, and starlight

Table 5: *V-band extra magnitudes to be subtracted from reference values of sky emission in Table 4, for bright, grey, and dark nights in La Palma [R.25].*

seeing		C	R1	R2	C+R1+R2
0.5”	Mean	58.7	40.9	0.4	100.0
	Std.dev.	1.4	1.4	0.2	0.0
	Std.dev.mean	0.3	0.3	0.0	0.0
0.6”	Mean	45.8	52.4	1.9	100.0
	Std.dev.	1.2	1.3	0.4	0.0
	Std.dev.mean	0.3	0.3	0.1	0.0
0.7”	Mean	36.0	59.0	4.9	100.0
	Std.dev.	1.4	1.2	0.8	0.1
	Std.dev.mean	0.3	0.3	0.2	0.0
0.8”	Mean	28.7	61.4	9.6	99.8
	Std.dev.	1.1	1.0	0.7	0.1
	Std.dev.mean	0.3	0.2	0.2	0.0
0.9”	Mean	24.0	60.4	14.9	99.3
	Std.dev.	1.3	1.7	1.5	0.2
	Std.dev.mean	0.3	0.4	0.3	0.1
1.0”	Mean	19.4	58.2	20.7	98.3
	Std.dev.	1.2	1.4	1.4	0.3
	Std.dev.mean	0.3	0.3	0.3	0.1
1.1”	Mean	17.0	54.1	25.3	96.4
	Std.dev.	1.2	1.7	1.2	0.4
	Std.dev.mean	0.3	0.4	0.3	0.1
1.2”	Mean	14.1	50.8	29.2	94.1
	Std.dev.	1.1	1.3	1.6	0.7
	Std.dev.mean	0.3	0.3	0.4	0.2
1.3”	Mean	11.8	47.2	32.0	91.0
	Std.dev.	1.0	1.7	1.6	0.9
	Std.dev.mean	0.2	0.4	0.4	0.2
1.4”	Mean	10.4	43.8	33.6	87.8
	Std.dev.	1.1	1.8	1.6	1.2
	Std.dev.mean	0.2	0.4	0.4	0.3
1.5”	Mean	9.2	39.8	35.1	84.1
	Std.dev.	0.9	1.3	1.4	1.3

	Std.dev.mean	0.2	0.3	0.3	0.3
1.6”	Mean	8.0	37.4	34.8	80.3
	Std.dev.	0.9	1.4	1.2	1.2
	Std.dev.mean	0.2	0.3	0.3	0.3
1.7”	Mean	7.2	33.9	35.3	76.3
	Std.dev.	0.8	2.0	1.9	0.9
	Std.dev.mean	0.2	0.5	0.4	0.2
1.8”	Mean	6.4	31.4	34.1	71.9
	Std.dev.	0.8	1.7	1.4	1.5
	Std.dev.mean	0.2	0.4	0.3	0.3
1.9”	Mean	6.0	28.9	33.3	68.2
	Std.dev.	0.8	1.3	1.2	1.4
	Std.dev.mean	0.2	0.3	0.3	0.3
2.0”	Mean	5.5	26.9	33.2	65.6
	Std.dev.	0.5	1.2	1.2	1.3
	Std.dev.mean	0.1	0.3	0.3	0.3

Table 6: Mean percentages of enclosed light per seeing FWHM (in arcsec) per zone.

7.2.5. Observational Setup

This parameter set describes the characteristics of the observation to be done with MEGARA:

1. Calculation mode: Choose between “Exposure time to SNR” and “SNR to exposure time”. The former calculates the SNR (inside various zones) from the input “Exptime per frame” (see below) (and number of frames). The latter calculates the exposure time required, per zone, to reach the input “Total SNR” (see below).

2. **Num. frames:** Number of frames (integer).

3. **Exptime per frame/Total SNR:** When “Calculation mode” is “Exposure time to SNR”, this field becomes the “Exposure time per frame in seconds”. The total exposure time will then be the product of “Num. frames” and the “Exptime per frame” values.

   This exposure time does not take into account instrument and telescope overheads (typically, 20-30% of the required exposure time; consult observing overheads section in GTC web page http://www.gtc.iac.es/observing/). If sky exposures are planned to be required in an observation in order to subtract sky emission, the user must also consider that the total exposure time required for that target could be up to twice the ETC estimates (plus overheads).

   When “Calculation mode” is “SNR to exposure time”, this field become the “Total SNR” (dimensionless).

4. **Number of sky fibers/bundles:** Number of sky fibers used to derive the sky spectrum to subtract. If the user has selected the Fiber MOS OM (§7.2.3), the maximum number of fibers is 644 (644/7=92 bundles), as each robotic positioner has a 7-fibers mini-bundle and there are 92 mini-bundles projected in the pseudo-slit corresponding to this OM [R.51]. In the case of the LCB IFU OM there are 8 fixed fiber bundles devoted to sky background measurements that are included into the pseudo-slit of this OM. Although 56 (8 x 7= 56 fibres) is the default value in this case, this number can be modified up to 623 fibres if the user considers that for his/her scientific case all the fibres need to be dedicated to the sky.

5. **Number of target fibers/bundles:** Number of fibers left after setting the 'Number of sky fibers'. The total number of fibers is determined by the OM as mentioned above.

6. **Line aperture:** Aperture to derive line flux in spectrum, in line FWHM units (n_{line}). This parameter is available only if the 'Input flux = Line + Continuum' option is set.

7. **Continuum aperture:** Aperture to estimate continuum around the line for continuum-subtraction, in line FWHM units (n_{CS}). This parameter is available only if the 'Input flux = Line + Continuum' option is set.

7.3. Outputs

A summary of the outputs of the ETC is provided here, with some warnings and extra information about the input source flux distribution. Since the current version to-date only provides SNR estimates, we have exclusively detailed them (§7.2.1). We remind the user that the current tool can be used to determine limiting fluxes in both continuum and line distributions just using the tool iteratively, changing the input values of flux until the required SNR on continuum or line and exposure time is provided as output.

7.3.1. Continuum output SNRs

The current version (v1.0.0) of the ETC provides the SNRs of the continuum input flux distribution expected for a given input parameters set for both, a single frame exposure and for the total number of frames N (SNR of a single frame multiplied by $\sqrt{N}$).

In the case of LCB, a table is provided for the continuum SNR: per voxel, per Å, and per collapsed/integrated spectrum) within different areas ('spaxel zones'): C (1 fiber), C+R1 (7 fibers), and C+R1+R2 (19 fibers).

In the case of MOS, the third column shows the SNR in the total source area instead of C+R1+R2.

The seeing that is used to compute the SNR depends on the source type: for a point source, we use seeing values computed assuming a Moffat profile for the PSF making the flux coming in each spaxel different (see *Table 6* for values and Section 7.4.3 for explanations), whereas for an extended source, we simply use the same flux (= net flux divided by the number of fibers required to cover the entire extended source) for each spaxel.

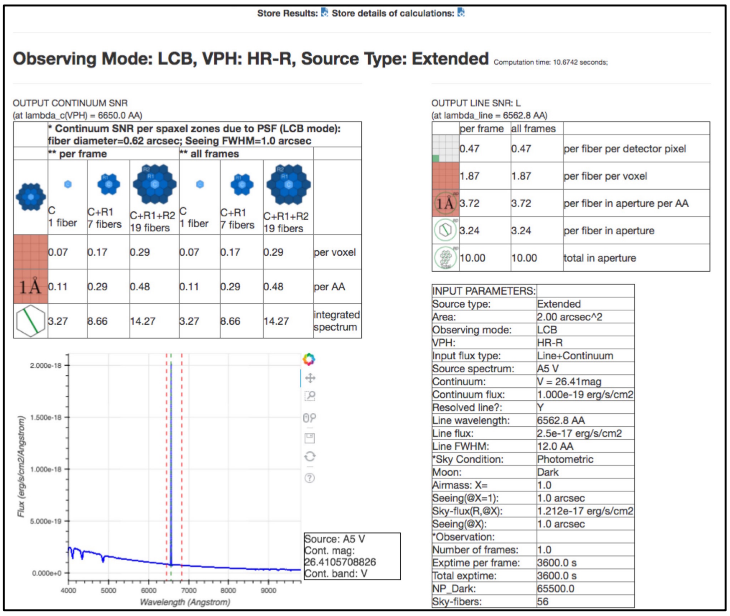


Figure 12: *Example output when input parameters are correct. A warning is given when the input parameters are incorrect, and no values are computed in that case (v.0.8.0, January 2017).*

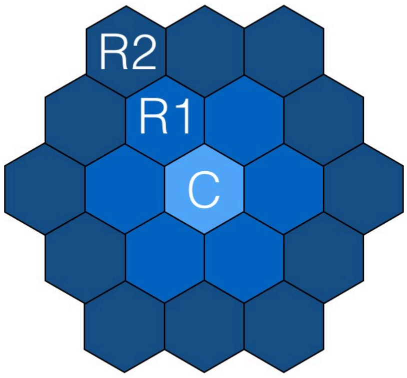


Figure 13: *As the PSF varies with the seeing, larger seeing results in the spread of light across several spaxels. When in "LCB IFU" mode, the output continuum SNR is computed for the light enclosed in the central spaxel (C), in the central spaxel plus its adjacent ring of 7 spaxels (C+R1), and in the central spaxel plus its adjacent ring of 7 spaxels plus the next adjacent ring (C+R1+R2).*

7.3.2. Line output SNRs

The current version of the ETC provides SNRs in an input line for an input parameters set.

In case we are dealing with a point source, the provided SNRs are for:

- in one fiber (spaxel), in the selected spectral aperture [(5)];

[5] Assuming the selected spectral apertures for line and continuum subtraction provided as inputs. If you

- in one fiber (spaxel), per Å;
- per voxel[(6,7)];
- per detector pixel[(8)].
- the total source area, in the selected line spectral aperture.

7.3.3. Graphical outputs

Graphical outputs can now be generated with the online ETC (see Figure 14). These plots are generated using an interactive Python library called *Bokeh* (details on the usage of the interactive plots are explained in the 'Quick Start guide' available by clicking on the "Quick Start" button). We plot the total continuum flux of the source (left) over the whole wavelength range of the instrument. The flux is calculated from the input spectrum, the continuum band, the input continuum magnitude (or flux). We also plot the resulting SNR per voxel (4 spatial pixels times 4 spectral pixels), computed at each wavelength over the VPH wavelength range. When "Num. frames" is larger than 1, the thin red line is the SNR per frame in 1 fiber, and the thick red line is the total SNR for the total exposure time in 1 fiber. Two more lines are shown, representing the SNR per frame for total area (thin blue), and for total exposure time (thick) for total area.

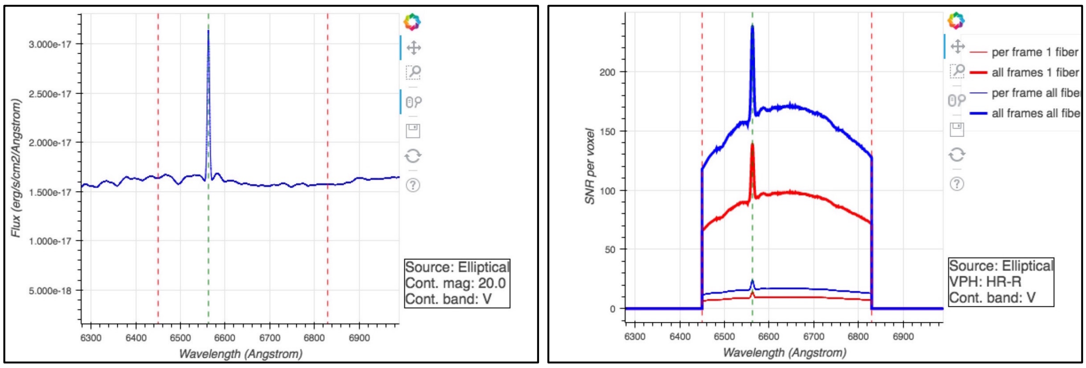


Figure 14: *Graphical outputs example. Left: source spectrum flux (in erg/s/cm²/Å) versus wavelength (in Å). Right: resulting SNR per voxel for: one frame and one fiber* ***(thin red)****, all frames and one fiber* ***(thick red)****, one frame and total area* ***(thin blue)****, and, all frames and total area* ***(thick blue)****.*

7.4. Physical model of the MEGARA ETC

7.4.1. Continuum SNRs formulae

The obtained formulas are based on those derived for the ETCs of ESO instruments [R.23,

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are interested in the SNR in 1 line FWHM, set the spectral apertures of line and continuum to 1 (i.e., to one line FWHM).

6 Assuming 4 spectral pixels as spectral aperture (i.e., the FWHM of the selected VPH).

7 A voxel is the minimum spatial and spectral resolution element sampled. In our case, one voxel is the projection of the whole fiber (minimum spatial resolution element) and of the VPH FWHM (minimum spectral resolution element) into 4×4 spectral pixels in the detector (see §3.20).

8 Assuming 1 spectral pixel as spectral aperture, the one with the best transmission in one voxel.

R.26]. The total number of photons received from a target between wavelengths (λ_1, λ_2) is given by:

$$S = \int_{\lambda_1}^{\lambda_2} \frac{\mathcal{F}_{\rm arc}(\lambda) \cdot T(\lambda) \cdot S_{\rm t} \cdot \Omega_{\rm obj} \cdot t_{\rm exp}}{E_\phi(\lambda)} \, d\lambda \qquad (11),$$

where F_{arc} (λ) is the flux per arcsec^2 of the target at each wavelength lambda, $T(\lambda)$ is the total transmission of the complete system at lambda, S_t is the telescope collecting area, Ω_{obj} is the target projected area contributing to the signal, E_ϕ (λ) is the energy of a photon with wavelength λ, and t_{exp} is the exposure time. If the input target flux is inserted in c.g.s units per arcsec^2 (i.e., in erg/s/cm^2/Å, see §6.3), then the telescope area must be in cm^2, the target projected area in arcsec^2, the photon energy in erg, the exposure time in seconds, and the wavelengths in Å. The wavelengths λ_1 and λ_2 correspond to the initial and final wavelengths of the considered wavelength range in the detector plane. The two extreme wavelength values considered can be written as:

$$\lambda_1 = \lambda_0 - \frac{\Delta\lambda}{2} \qquad\qquad \lambda_2 = \lambda_0 + \frac{\Delta\lambda}{2} \qquad , (12)$$

being $\Delta\lambda = \lambda_2 - \lambda_1$ the considered wavelength range width, and λ_0 the central wavelength of this range. In the case of continuum, we consider that the wavelength range is always centered on the effective wavelength of the user-selected VPH (see *Table 1*).

In the case of a point source, the projected area of a source on the sky is the seeing disk. Assuming that all the flux of a point source is uniformly distributed into a circle of diameter equal to the seeing FWHM, the projected area of the point source is:

$$\Omega_{\rm obj} = A_{\rm seeing} \qquad , (13)$$

being A_{seeing} the area of the seeing given by the following equation:

$$A_{\rm seeing} = \pi \left(\frac{\rm FWHM}{2}\right)^2 \qquad . (14)$$

Several possibilities have been considered for different Ω_{obj} depending on the output SNR (or exposure time) considered (see §7.4.2). The values assigned in each case to Ω_{obj} are listed in *Table 7* and *Table 8* in §7.4.2.

In the case of point sources, the user is requested to provide the total continuum flux in a certain band i as input F_i. Using the user-selected spectrum template and the selected VPH, MEGARA ETC derives the energy flux spectrum of the source $F(\lambda)$ (in erg/s/cm^2/Å, see §6.3). Then, the energy flux per arcsec^2 of the source can be derived just dividing by the source projected size (i.e., the projected area of the seeing disk if it is a point source):

$$\mathcal{F}_{\rm arc}(\lambda) = \mathcal{F}(\lambda)/A_{\rm seeing}$$.(15)

If the target is extended, the user-provided total continuum flux in a given input i band, F_i, should be provided per arcsec^2 (or, equivalently, the total continuum magnitude provided by the user is already per arcsec^2). Therefore, no normalization is required to get $F_{arc}(\lambda)$, once the selected template spectrum is adequately scaled to the input flux in the input i band (see §6.3).

The total transmission of the system accounts for the transmissions of the atmosphere $T_{atm}(\lambda)$, the telescope $T_{tel}(\lambda)$, and the instrument $T_{ins}(\lambda)$, as well as for the quantum efficiency of the detector $q_e(\lambda)$, as follows:

$$T_{\rm ins}(\lambda) = T_{\rm optics}(\lambda) \cdot T_{\rm VPH}(\lambda) \cdot T_{\rm fibre}(\lambda)$$,(16)

The transmission of the instrument considers the transmission of the optics at the current optical design ($T_{optics}(\lambda)$, see §6.2.2), the VPHs transmission ($T_{VPH}(\lambda)$, consult §6.2.3), and the fibers ($T_{fiber}(\lambda)$) in the following way:

$$T(\lambda) = T_{\rm atm}(\lambda) \cdot T_{\rm tel}(\lambda) \cdot T_{\rm ins}(\lambda) \cdot q_{\rm e}(\lambda)$$,(17)

The collecting area of the telescope is easily computed assuming the effective radius of the GTC telescope ($R_{t,eff}$ = 485.8 cm), through:

$$S_{\rm t} = \pi \cdot R^2_{\rm t,eff}$$,(18)

The energy of a photon of wavelength λ is provided by the following equation:

$$E_\phi = \frac{hc}{\lambda}$$,(19)

being h the Planck constant (h=6.62606885 $\times 10^{27}$ ergs/s), and c the light speed (c=2.99792458 $\times 10^{10}$ cm/s). If the previous units are used, λ must be provided in cm.

Equivalently, the number of photons received from the sky emission (together with those coming from the source) will be:

$$S_{\rm sky} = \int_{\lambda_1}^{\lambda_2} \frac{\mathcal{F}_{\rm arc,sky}(\lambda) \cdot T(\lambda) \cdot S_{\rm t} \cdot \Omega_{\rm obj,sky} \cdot t_{\rm exp}}{E_\phi(\lambda)} \, d\lambda \quad ,(20)$$

where $F_{arc,sky}$ (λ) is the sky flux per $arcsec^2$ at each wavelength lambda, and $\Omega_{obj,sky}$ is the sky projected area contributing to the target signal S in $arcsec^2$. Again, depending on the output SNR that we have considered, $\Omega_{obj,sky}$ adopts different values (consult *Table 7* and *Table 8* in §7.4.2 for the value used in each case for this parameter).

The error in the measurement of the signal S in Eq. 11 will be mainly due to the typical Poissonian error entailed by the source signal and the associated sky signal, to the readout noise, to the dark current, and to the error associated to the measurement of the sky signal and dark current. So, we can consider that the noise N of the signal S can be expressed as the quadratic sum of the various (independent) noise contributions [R.23, R.27]:

$$N = \sqrt{S + S_{\rm sky} + S_{\rm dark} + S_{\rm RON} + N_{\rm SM}^2 + N_{\rm DM}^2} \quad .(21)$$

In the previous expression, we have already considered that the noise to the square associated to any photon signal (coming from the source, the sky, the dark current, or from the readout noise) is the signal itself S, i.e.: $\sigma_S^2=S$, $\sigma_{sky}^2=S_{sky}$, $\sigma_{dark}^2=S_{dark}$, and $\sigma_{RON}^2=S_{RON}$.

The source and the sky signals are given by Eqs. 11 and 20. The dark signal can be computed through the following expression:

$$S_{\rm dark} = t_{\rm exp} \cdot {\rm DARK} \cdot n_{\rm pix,obj} \quad ,(22)$$

where *DARK* is the value of the detector dark current in electrons/pix/s and $n_{pix,obj}$ is the number of detector pixels of the source considered in the detector plane. This last number is given by:

$$n_{\rm pix,obj} = n_{\rm pix,y} \cdot n_{\rm pix,x} \quad ,(23)$$

being $n_{pix,y}$ and $n_{pix,x}$ the number of pixels considered in the spatial (y) and spectral (x) directions of the detector (whose values depend on the considered SNR case for being provided as output, as listed in *Table 7* and *Table 8* of §7.4.2).

The readout noise signal is:

$$S_{\rm RON} = n_{\rm pix,obj} \cdot {\rm RON}^2 \quad ,(24)$$

being *RON* the rms of the detector readout noise in electrons.

The terms N^2_{SM} and N^2_{DM} in Equation 21 provide the error terms associated to the measurement of the sky signal and dark current (both of which scale inversely with the number of pixels used to determine them) and to the subsequent subtraction of these measured values to the obtained data, after applying the proper scaling to the considered target or sky projected area.

The average value of the sky measurement is scaled to the input data multiplying by the factor ($\Omega_{obj,sky}/\Omega_{sky}$), and thus the propagated error associated to the subtraction of this scaled value will be:

$$N_{\rm SM}^2 = \left(\frac{\Omega_{\rm obj,sky}}{\Omega_{\rm sky}}\right)^2 \cdot \left[S_{\rm SM} + n_{\rm sky} \cdot ({\rm RON})^2 + n_{\rm sky} \cdot {\rm DARK} \cdot t_{\rm exp}\right] \quad ,(25)$$

Equivalently to Eq. 21, the error associated to the sky measurement can be written as the quadratic sum of those (independent) error sources present in the measurement process: the Poissonian error associated to the sky photon flux, that due to the dark current, and that derived from the readout noise (that corresponds to the addends inside the square brackets in the previous equation, respectively). The measured sky signal will be given by an expression similar to Eq. 20, but considering the total sky projected area used for determining it, Ω_{sky}:

$$S_{\rm SM} = \int_{\lambda_1}^{\lambda_2} \frac{\mathcal{F}_{\rm arc,sky}(\lambda) \cdot T(\lambda) \cdot S_{\rm t} \cdot \Omega_{\rm sky} \cdot t_{\rm exp}}{E_\phi(\lambda)}\, d\lambda \quad . (26)$$

Here, $F_{arc,sky}(\lambda)$ represents the energy flux per arcsec^2 of the sky. The total sky area used Ω_{sky} depends on the number of sky fiber mini-bundles $N_{sky,bundles}$ considered by the user, as:

$$\Omega_{\rm sky} = N_{\rm sky,fibers} \cdot A_{\rm fibre} \quad ,(27)$$

where $N_{sky,fibers}$ is the total number of sky fibers used ($N_{sky,fibers}$ = 7 fibers × $N_{sky,bundles}$), and A_{fiber} is the sky-projected area of a MEGARA fiber (see §3.4).

The term n_{sky} in Eq. 25 represents the number of detector pixels used to derive the sky signal measurement, and it is equal to the product of the pixels considered in the spectral direction ($n_{sky,x}$) by the number of pixels considered in the spatial direction ($n_{sky,y}$):

$$n_{\rm sky} = n_{\rm sky,y} \cdot n_{\rm sky,x} \quad , (28)$$

where $n_{sky,x}=n_{pix,x}$ because in both cases we are considering the same spectral range, and $n_{sky,y}=4\times N_{sky,fibers}$ because we are considering the projected spectra of all the used sky fibers and each fiber projects onto 4 pixels in the spatial direction (y) of the detector [R.5, R.12]. The adopted value of $n_{pix,x}$ depends on the case of output SNR/t_{exp} considered. The values assigned to this paremeter for each output SNR/t_{exp} case are listed in *Table 7* and *Table 8* of §7.4.2.

The average value of the measured dark is scaled to the input data by the factor ($n_{pix,obj}/n_{pix,dark}$), being $n_{pix,dark}$ the number of pixels used to determine the dark current. Therefore, the propagated error associated to the subtraction of this scaled value will be:

$$N_{\rm DM}^2 = \left(\frac{n_{\rm pix,obj}}{n_{\rm pix,dark}}\right)^2 \cdot \left[t_{\rm exp} \cdot {\rm DARK} \cdot n_{\rm pix,dark} \cdot + n_{\rm pix,dark} \cdot ({\rm RON})^2\right] \quad . (29)$$

In the previous expression, the first addend into the square brackets represents the dark signal measured to determine the average dark signal, while the second addend is the readout noise entailed by this measurement.

Once we have estimated Equations 11 and 21, the SNR of the continuum of the input source can be derived just dividing the signal by the noise:

$$\mathrm{SNR} = \frac{S}{N} \quad . \qquad (30)$$

Note that these same expresions are used to relate the required exposure time when the flux of the source and the SNR are both fixed (see also Section 7.4.5).

7.4.2. Spectral and spatial parameters for continuum SNR estimates

In the present version of MEGARA ETC, the flux in a fiber is assumed to be projected uniformly along 4 pixels in the spatial direction of the detector. The spectral projection of the fiber on the detector is assumed to be uniform too. Nevertheless, the total signal in the voxel is quite similar considering this uniform flux distribution and a more realistic one, so we do not expect a significant change in the estimates assuming corrections due to the different distribution of one fiber flux onto each one of these 4 pixels (because of the geometric section of the projection of the fiber on the detector across the spatial direction) [R.47], although they could be considered in future versions.

However, the current tool estimates the SNR in the central pixel of the voxel in the spatial direction, considering the percentage of flux corresponding to it: 32.82% in the fibers of 100 microns, for the 4 spectral pixels in a voxel [R.47]. This means that the output SNR estimates per pixel on the detector provide the maximum SNR achieved in one of the pixels in a voxel.

In Table *7*, we show the values assigned to the different parameters in Equations 11-30 for deriving the output continuum SNRs provided by MEGARA ETC for ***point*** sources. Different spatial and spectral elements onto the detector have been considered, as well as different projected areas on the punctual source contributing to the signal. The central wavelength λ_0 in all the cases will correspond to the effective wavelength of the selected VPH. In Table *7*, D represents the dispersion of the selected VPH, PS is the MEGARA detector plate scale (PS = 0.17 arcsec/pix), ΔB is the width of the spectral range of the VPH, and A_{fiber} and $R_{eff,fiber}$ are the projected area and the "effective" radius of the hexagonal fiber in arcsec^2, respectively (consult §3.4). The effective radius of the hexagonal fiber corresponds to the radius of a circular fiber with the same area of the cross section as our hexagonal fiber, i.e.:

$$R_{eff,fiber} = \sqrt{\frac{3\sqrt{3}}{2\pi}} L_{spaxel} \quad . \qquad (31)$$

For the parameters related to the user-selected VPH see *Table 1*.

In Table *8*, we show the values assigned to the different parameters in Equations 11-30 for deriving the output continuum SNRs provided by MEGARA ETC for ***extended*** sources. As in the case of point sources, different spatial and spectral elements onto the detector have been considered, as well as different projected areas on the extended source contributing to the signal. Again, the central wavelength λ_0 is assumed to correspond to the effective wavelength of the selected VPH. In Table *8*, the parameters *D*, *ΔB*, A_{fiber} and $R_{eff.fiber}$ represent the same as in Table *7*.

If the source is extended, the problem can be translated to a point source problem in the following cases:

- If input target is extended and its diameter [9] is lower than the input seeing FWHM (i.e., if $R_{source} < FWHM/2$).
- If the target is extended and its diameter [9] and the seeing FWHM are contained within a fiber (i.e., if $R_{source} < R_{fiber}$ and $FWHM/2 < R_{fiber}$).

If any of these two cases occurs, a warning is sent to the user.

7.4.3. Moffat Point-Spread-Function for a more accurate SNR

When the source type is a Point source, a Moffat PSF is used to simulate the seeing according to its FWHM and to obtain the fraction of enclosed light in the central, and surrounding rings of spaxels (up to two rings) (see Figure 13).

We have performed Monte Carlo simulations of the PSF to see how much light falls onto the central spaxel, then onto the first spaxel ring (6 spaxels) around it, and finally onto the second spaxel ring (12 spaxels). To do so, we have used FiberSpecSim (available at http://t-rex.fis.ucm.es/fiberspecsim/wform.html) (Author: Belén Alcalde Pampliega). We used the following input parameters:

- The spectrograph: GTC [MEGARA]
- Seeing FWHM [arcsec]: 0.5" to 2.0"
- Airmass: 1.0
- Initial lambda [nm]: 350
- Final lambda [nm]: 450
- Fiber-core size [µm]: 100
- Rings/[rows/cols]: 2
- Spaxel size [arcsec]: 0.62
- Spaxel shape: Hexagonal
- Number of Monte Carlo particles: 1000
- Speed factor: 1000

Since FiberSpecSim does not allow very large number of particles, we made 20 simulations each with a 1000 particles for each of the seeing value. Averaging the results, we get the mean,

[9] The extended sources are assumed to exhibit a circular projected area. The radius of an extended source is derived from the input source area as follows: $R_{source} = \sqrt{(A_{source}/\pi)}$

the standard deviation, and the standard deviation of the mean of the percentage of the enclosed light within each region (central, ring1, ring2) for each seeing. In any case, the standard deviation of the mean is less than 0.5%. Hence, we use the mean (of the 20 trials) as fixed values. Results are shown in *Table 6*.

7.4.4. Batch Processing

As of version 1.0.0, it is possible to calculate the SNR per frame per voxel for the spaxel C, C+R1, and C+R1+R2 (see section 7.3.1). This feature only works when the Target type (i.e. Source type) is set to "Point source", and is limited to 92 targets. The user can therefore obtain 276 different SNR in one form submission. The input list should be copy/pasted or directly typed in the text field below the "Batch process?" yes/no buttons. The input requires three columns, in comma-separated value (CSV) format (see Section 7.2.2). The output is stored in a CSV file and can be retrieved by clicking on the "Store batch process results (CSV)" button.

Here is an example input:

```
#name, band, Vegamag
V* T Dra,B,18.08
LHS 1903,V,12.21
GD 299,B,11.824
```

In this example, the first row will not be read as it contains a "# (sharp)" character. Note that the magnitude should be given in the Vega mag system. Spaces are treated as strings and should be avoided in the second and third columns. Empty lines should also be avoided.

7.4.5. Calculation Mode

The calculation mode can now be changed between "Exposure time to SNR" and "SNR to Exposure time". The former is the default way of calculating the SNR from an input exposure time and the total number of frames. The latter is based on the former calculation, but uses the bisection method to narrow down the closest value by iteration (limited to a maximum of 20). If the solution does not converge after 20 iterations, the exposure time will be erroneous and gives a negative value. Output exposure times are given in the result table in units of second.

For example, if the "Total SNR" input is set to 10 and the number of frame is set to 10, then the exposure time outputs will correspond to how much exposure time is required to reach SNR=10 with all the frames, or to reach SNR=10/sqrt(10)=3.16 per frame.

***Table 7:** Values assigned to different photometric parameters in order to derive the output continuum SNRs provided by the MEGARA ETC for point sources.*

<table>
<tr><td colspan="2">VALUES OF SPECTRAL AND SPATIAL PARAMETERS TO OBTAIN DIFFERENT CONTINUUM SNRs FOR POINT SOURCES [(*)]</td><td colspan="3">No. of pixels in the detector spectral direction (x)</td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td>FWHM of VPH:
$\Delta\lambda = 4D$
$n_{pix,x} = 4$ pixels</td><td>N_{pix} in 1 Å:
$\Delta\lambda = 1$ Å
$n_{pix,x} = 1/D$</td><td>N_{pix} in whole spectrum:
$\Delta\lambda = \Delta B$
$n_{pix,x} = \Delta B/D$</td><td colspan="2"></td></tr>
<tr><td>Source and sky projected area contributing to emission in the projected element considered</td><td>Total source area:
$\Omega_{obj} = A_{seeing}$
Sky emission:
- If $FWHM < 2R_{fiber} \Rightarrow \Omega_{obj,sky} = A_{fiber}$
- If $FWHM \geq 2R_{fiber} \Rightarrow \Omega_{obj,sky} = A(N_{fibers})$ [(**)]</td><td></td><td></td><td>Total SNR of source, λ-collapsed spectrum</td><td>N_{pix} in total projected source in y[(**)]:
- If $FWHM < 2R_{fiber} \Rightarrow n_{pix,y} = 2R_{eff,fiber}/PS$
- If $FWHM \geq 2R_{fiber} \Rightarrow n_{pix,y} = N_{fibers} \times [2 \times R_{eff,fiber}/PS]$</td><td>No. of pixels considered in the detector spatial direction (y)</td></tr>
</table>

	Source emission in 1 projected fiber: - If $FWHM < 2R_{fiber} \Rightarrow \Omega_{obj}=A_{seeing}$ - If $FWHM \geq 2R_{fiber} \Rightarrow \Omega_{obj}=A_{fiber}$ Sky emission: $\Omega_{obj,sky}= A_{fiber}$	SNR in 1 fiber, per FWHM of VPH **(1 voxel)**	SNR in 1 fiber, per Å	SNR in 1 fiber, λ-collapsed spectrum **(1 spaxel)**	N_{pix} in one projectedfiber in y (4 y-pixels): $n_{pix,y} = 2\ R_{eff,fiber}/PS = 4$ pixels	
		1 x-pixel: $\Delta\lambda = 1D$, $n_{pix,x} = 1$ pixel				
	Source emission in 1 y-pixel of a projected fiber(***): *- If $FWHM < 2R_{fiber} \Rightarrow \Omega_{obj}=A_{seeing}$* – *If $FWHM \geq 2R_{fiber} \Rightarrow$ S(in 1 y-pixel) = S(in 1 spaxel /[no. Pixels in one voxel] if uniform distribution* – *If not, 32.82% in the fibers of 100 micron divided into the number of pixels of the FWHM in the spectral direction* Sky emission: *S_{sky}(in 1 y-pixel) = S_{sky} (in 1 spaxel)/[no. Pixels in one voxel/*spaxel*]*	SNR in 1 detector pixel (the central one of the voxel, considering the maximum flux distribution within the spatial profile of a projected fiber)			1 y-pixel: $n_{pix,y} = 1$ pixel	

Table notes:

(*) The flux in a fiber is assumed to be projected uniformly along 4 pixels in the spatial direction of the detector. The spatial projection of the fiber on the detector is assumed to be flat, except for the estimates in one pixel, in which the pixel with the maximum signal in a voxel is provided.

(**) The area of all the required fibers to ensure a complete coverage of the source will be noted $A(N_{fibers})$ hereafter. In this case, this area is: $A(N_{fibers})=A_{fiber}\ N_{fibers}$, where N_{fibers} computes the integer number of fibers required to cover the seeing disk. We will note as "FLOOR" to the function that returns the nearest and highest integer of a given decimal value, then: N_{fibers} = FLOOR(A_{seeing}/A_{fiber}).

(***) The signal in one detector pixel is computed from the signal in one voxel, considering that the light distribution in the spatial profile of a voxel has a maximum of flux in its central pixel of 32.82% in the fibers of 100 micron, for all the pixels in the voxel in the spectral direction.

Table 8*: Values assigned to different photometric parameters in order to derive the output continuum SNRs provided by the MEGARA ETC for extended sources***.**

VALUES OF SPECTRAL AND SPATIAL PARAMETERS TO OBTAIN DIFFERENT CONTINUUM SNRs FOR EXTENDED SOURCES[(*)]		**No. of pixels considered in the detector spectral direction (x)**				
		FWHM of VPH: $\Delta\lambda = 4D$ $n_{pix,x} = 4$ pixels	N_{pix} in 1 Å: $\Delta\lambda = 1$ Å $n_{pix,x} = 1/D$	N_{pix} in whole spectrum: $\Delta\lambda = \Delta B$ $n_{pix,x} = \Delta B/D$		
Source and sky projected area contributing to emission in the considered projected element	Total source area: $\Omega_{obj} = A_{obj}$ (user input) Sky emission[(**)]: $\Omega_{obj,sky} = A(N_{fibers})$			Total SNR of source, λ-collapsed spectrum	N_{pix} in total projected source in y[(**)]: $n_{pix,y} = N_{fibers} \times [2\times R_{eff,fiber}/PS]$	**No. of pixels considered in the detector spatial direction (y)**
	Source emission in 1 projected fiber: $\Omega_{obj} = A_{fiber}$ Sky emission: $\Omega_{obj,sky} = A_{fiber}$	SNR in 1 fiber, per FWHM of VPH **(1 voxel)**	SNR in 1fiber, per Å	SNR in 1 fiber, λ-collapsed spectrum **(1 spaxel)**	N_{pix} in 1 spaxel in y (4 y-pixels): $n_{pix,y} = 2R_{eff,fiber}/PS = 4$ pixels	
	Emission in 1 arcsec²: - If $A_{obj} < 1\ arcsec^2 \Rightarrow \Omega_{obj} = A_{obj}$ - If $A_{obj} \geq 1\ arcsec^2 \Rightarrow \Omega_{obj} = 1\ arcsec^2$ Sky emission: $\Omega_{obj,sky} = 1\ arcsec^2$		SNR per arcsec per Å on the detector	SNR in 1 arcsec², λ-collapsed spectrum	N_{pix} in 1 y-projected arcsec²: $n_{pix,y} = FLOOR[1arcsec^2/A_{fiber}] \times [2\times R_{eff,fiber}/PS]$	
		1 x-pixel: $\Delta\lambda = D$, $n_{pix,x} = 1$ pixel				

	Source emission in 1 y-pixel of a projected fiber(***): - *If FWHM* $< 2R_{fiber} \Rightarrow \Omega_{obj}=A_{seeing}$ - *If FWHM* $\geq 2R_{fiber} \Rightarrow$ *(in 1 y-pixel) = S(in 1 spaxel /[no. Pixels in one voxel] if uniform distribution.* *If not, 32.82% in the fibers of 100 micron divided into the number of pixels of the FWHM in the spectral direction.* Sky emission: S_{sky}*(in 1 y-pixel)* = S_{sky} *(in 1 spaxel)/[16 pix/sp*x]	SNR in 1 detector pixel (the central one of the voxel, considering the maximum flux distribution within the spatial profile of a projected fiber)	1 y-pixel: $n_{pix,y} = 1$	

Table notes:

(*) The projected area of the extended source is assumed to be circular.

(**) The area of all the required fibers to ensure a complete coverage of the source will be noted $A(N_{fibers})$ hereafter. In this case, this area is: $A(N_{fibers})=A_{fiber}\, N_{fibers}$, where N_{fibers} computes the integer number of fibers required to cover the source. We will note as "FLOOR" to the function that returns the nearest and highest integer of a given decimal value, then: N_{fibers} = FLOOR(A_{obj}/A_{fiber}).

7.4.6. Line SNRs formulae

The formulas for deriving SNRs of an emission line are equivalent to those derived for the continuum emission (see §7.4.1). Now, the signal (i.e., the number of photons) detected by GTC+MEGARA in the selected configuration in the whole line (independently of the line FWHM, $FWHM_{line}$, which is a user-selected input, see §4) is:

$$S_{\rm line} = \frac{\mathcal{F}_{\rm arc}(\lambda_0) \cdot T(\lambda_0) \cdot S_{\rm t} \cdot \Omega_{\rm obj} \cdot t_{\rm exp}}{E_\phi(\lambda_0)} \quad , (32)$$

being $T(\lambda_0)$ the transmission of the whole system at the line wavelength λ_0 (see Equations 16-17, S_t the telescope collecting area (see Eq. 18), Ω_{obj} is the target projected area contributing to the signal, E_φ (λ_0) is the energy of a photon with wavelength λ_0 (see Eq. 19), and t_{exp} is the exposure time.

In this case, the line wavelength λ_0 is given by the user as input. $F_{arc}(\lambda_0)$ is the energy flux emitted by the target at the line wavelength per arcsec^2. The user is requested to provide as input the integrated energy flux of the line if the object is a point source, $F(\lambda_0)$, or per arcsec^2 if the source is extended, $F_{arc}(\lambda_0)$. In the former case, its projected area is determined by the seeing disk. Again, $F_{arc}(\lambda_0)$ is estimated from $F(\lambda_0)$ and the input FWHM of the seeing through Equations 13-15.

Several possibilities have been considered for different Ω_{obj} depending on the output SNR that we have considered (see §7.4.7). The values assigned in each case to Ω_{obj} are listed in *Table 9* and *Table 10* in §7.4.7.

The noise contributing to the line signal in the considered spectral aperture (provided as input by the user in $FWHM_{line}$ units, see §6) will be given by the square root of the quadratic summation of all the independent noise sources contributing to the derivation of the line signal in the spectrum:

$$N_{\rm line} = \sqrt{S_{\rm line} + S_{\rm cont} + S_{\rm dark} + S_{\rm RON} + N_{\rm CS}^2 + N_{\rm DS}^2} \quad .(33)$$

The first four addends inside the square root correspond to the photon noises associated to the line signal, continuum signal, dark current, and readout noise in the considered spectral aperture, respectively. N_{CS} and N_{DS} symbolize the noises due to continuum-subtraction using the continuum spectral aperture (provided by the user as input, in $FWHM_{line}$ units, see §7) and dark-subtraction in the spectrum, respectively.

Let us call $\Delta\lambda_{line}$ to the line spectral aperture considered on the detector. This aperture can adopt different values, depending on the output SNR that we are interested in (it can be one spectral pixel, one Å, one $FWHM_{line}$, or the user-selected line spectral aperture, see §7.4.7 for the values used in each output case). If the user-selected spectral aperture is used, then this line spectral aperture is given by:

$$\Delta\lambda_{\rm line} = n_{\rm line} \cdot {\rm FWHM}_{\rm line}$$,(34)

where n_{line} is the number inserted by the user of line FWHMs to be considered around the central line wavelength as aperture for deriving the line signal (see §6). The user-selected spectral aperture for continuum subtraction $\Delta\lambda_{CS}$ is computed in a similar way, through:

$$\Delta\lambda_{\rm CS} = n_{\rm CS} \cdot {\rm FWHM}_{\rm line}$$, (35)

being n_{CS} the number of line FWHMs considered by the user to subtract continuum emission (see §7).

The continuum signal inside this aperture will contribute to the line noise, according to Eq. 33. This can be estimated similarly to Eq. 11, but now considering the spectral aperture around the line wavelength λ_0:

$$S_{\rm cont} = \int_{\lambda_0-\Delta\lambda_{\rm line}/2}^{\lambda_0+\Delta\lambda_{\rm line}/2} \frac{\mathcal{F}_{\rm arc}(\lambda) \cdot T(\lambda) \cdot S_{\rm t} \cdot \Omega_{\rm obj} \cdot t_{\rm exp}}{E_\phi(\lambda)} \, d\lambda$$.(36)

The dark signal S_{DARK} in Eq. 33 can be estimated as follows:

$$S_{\rm dark} = t_{\rm exp} \cdot {\rm DARK} \cdot n_{\rm pix,\Delta\lambda_{line}}$$, (37)

where we must account for the number of pixels considered on the detector $n_{pix,\Delta\lambda line}$. This depends on the number of pixels considered in the spectral and spatial directions of the detector:

$$n_{\rm pix,\Delta\lambda_{line}} = n_{\rm pix,x}(\Delta\lambda_{\rm line}) \cdot n_{\rm pix,y}$$. (38)

The number of pixels in the spectral direction $n_{pix,x}(\Delta\lambda_{line})$ depends directly on the spectral aperture considered through the dispersion of the selected VPH (D), according to:

$$n_{\rm pix,x}(\Delta\lambda_{\rm line}) = \Delta\lambda_{\rm line}/D$$. (39)

Different values of $n_{pix,x}(\Delta\lambda_{line})$ and $n_{pix,y}$ depending on the considered spectral aperture and spatial elements to provide the output line SNR are listed in *Table 9* and *Table 10* in §7.4.7.

The readout signal S_{RON} in Eq. 33 will also depend on the number of pixels considered on the detector, as:

$$S_{\rm RON} = n_{\rm pix,\Delta\lambda_{line}} \cdot {\rm RON}^2 \quad . (40)$$

The noise due to continuum-subtraction obtained in the aperture $\Delta\lambda_{CS}$ must be scaled to aperture where the signal is estimated $\Delta\lambda_{line}$, by multiplying by the factor ($\Delta\lambda_{line}/\Delta\lambda_{CS}$). This implies that the propagated error associated to the subtraction of this scaled value will be:

$$N_{\rm CS}^2 = \left(\frac{n_{\rm line}}{n_{\rm CS}}\right)^2 \cdot N_{\rm cont}^2(\Delta\lambda_{\rm CS}) \quad (41)$$

In the previous expression, $N^2_{cont}\ (\Delta\lambda_{CS})$ represents the squared noise corresponding to the continuum in a spectral aperture $\Delta\lambda_{CS}$ on the detector, which is estimated through Eq. 21, as indicated in §7.4.1. For this computation, the continuum-spectrum aperture $\Delta\lambda_{CS}$ must be assumed in order to estimate all the contributions to $N^2_{cont}\ (\Delta\lambda_{CS})$ (see §7.4.1). In particular, the first addend inside the square root in Eq. 21 (the continuum signal, *S*) would be in this case:

$$S_{\rm cont} = \int_{\lambda_0-\Delta\lambda_{\rm CS}/2}^{\lambda_0+\Delta\lambda_{\rm CS}/2} \frac{\mathcal{F}_{\rm arc}(\lambda)\cdot T(\lambda)\cdot S_{\rm t}\cdot\Omega_{\rm obj}\cdot t_{\rm exp}}{E_\phi(\lambda)}\,d\lambda \quad (42)$$

The number of pixels, $n_{pix,\Delta\lambda CS}$, to be considered when estimating $N^2_{cont}\ (\Delta\lambda_{CS})$ will be:

$$n_{\rm pix,\Delta\lambda_{CS}} = n_{\rm pix,x}(\Delta\lambda_{\rm CS})\cdot n_{\rm pix,y} \quad , (43)$$

where $n_{pix,x}$ is set by the continuum-subtraction aperture selected by the user through:

$$n_{\rm pix,x}(\Delta\lambda_{\rm CS}) = \Delta\lambda_{\rm CS}/D \quad . (44)$$

The last term inside the square root of Eq. 33 (the noise due to dark subtraction) will be:

$$N_{\rm DS}^2 = \left(\frac{n_{\rm pix,\Delta\lambda_{line}}}{n_{\rm pix,dark}}\right)^2 \cdot \left[t_{\rm exp}\cdot{\rm DARK}\cdot n_{\rm pix,dark}\cdot + n_{\rm pix,dark}\cdot({\rm RON})^2\right] \quad , (45)$$

where the term ($n_{pix,\Delta\lambda line}/n_{pix,dark}$) comes from the scaling of the average dark signal computed to the number of pixels in the considered spectral aperture (this is analogous to Eq. 29).

Finally, the output line SNR is estimated through Eqs. 32 and 33, as follows:

$${\rm SNR}_{\rm line} = \frac{S_{\rm line}}{N_{\rm line}} \quad . (46)$$

7.4.7. Spectral and spatial parameters for line SNR estimates

As commented in §7.4.2, in the present version of MEGARA ETC, the flux in a fiber is assumed to be projected uniformly along 4 pixels in the spatial direction of the detector, and the spatial projection of the fiber on the detector is assumed to be flat. This provides a good approximation for total SNR estimates in a voxel or in one spaxel. Corrections due to the different distribution of one fiber flux onto each one of these 4 pixels (because of the geometric section of the fiber) will be implemented in future versions. Anyway, the SNR per detector pixel is provided for the central pixel of the voxel, which accumulates 32.82% of the flux in the fibers of 100 microns considering the Gaussian distribution of light in the spatial direction in one voxel, integrated for the 4 spectral pixels in a voxel [R.47]. This means that the output SNR estimates per pixel on the detector provide the maximum SNR achieved in one of the pixels in a voxel.

In *Table 9* and *Table 10*, we list the values assigned to the different parameters in Equations 32-46 for deriving the output line SNRs provided by MEGARA ETC for *point* and *extended* sources, respectively. Different spatial and spectral elements onto the detector have been considered, as well as different projected areas on the source contributing to the signal. The central wavelength λ_0 in all the cases corresponds to the line wavelength (input provided by the user). In the Tables 9 and 10, D represents the dispersion of the selected VPH, PS is the MEGARA detector plate scale (PS = 0.17 arcsec/pix), $\sigma_{\rm line}$ is the line FWHM[10] (also provided by the user, see §11), and A_{fiber} and $R_{eff,fiber}$ are the area and the "effective" radius of the hexagonal fiber, respectively (see eq. 31). For the parameters related to the user-selected VPH, see *Table 1*.

As noted above, if the source is extended, the problem can be translated to a point source problem in the following cases:

- If input target is extended and its diameter(9) is lower than the input seeing FWHM (i.e., if R_{source} < FWHM/2).
- If the target is extended and its diameter and the seeing FWHM are contained in a fiber (i.e., if $R_{source} < R_{fiber}$ and FWHM/2< R_{fiber}).

If any of these two cases occurs, a warning indicating this is sent to the user.

If the output SNR is assuming 1 Å as spectral aperture, then the line signal per Å on the detector in the considered spatial element can be estimated through:

$$S_{\rm line,\mathring{A}} = \frac{S_{\rm line}}{\rm FWHM_{line}} \quad , (47)$$

where S_{line} has been estimated through Eq. 32 and $\rm FWHM_{line}$ is a user input (see §4).

[10] We will note the line FWHM as $\sigma_{\rm line}$ or $\rm FWHM_{line}$ indistinctly.

If a spectral aperture of 1 spectral pixel were considered instead, the signal per spectral pixel in the considered spatial element would be:

$$S_{\mathrm{line,spect-pix}} = S_{\mathrm{line,\mathring{A}}} \cdot D \qquad .(48)$$

However, note that we provide the SNR in the central pixel of the voxel considering that it concentrates 32.82% of the flux in the fibers of 100 microns, according to the Gaussian distribution of light in the spatial direction in one voxel [R.47]. The previous value considers a uniform distribution of light in both the spatial and spectral direction of the voxel. Therefore, this value is thus scaled to account for this.

Table 9*: Values assigned to different photometric parameters in order to derive the output line SNRs provided by the MEGARA ETC for point sources.*

<table>
<tr><td colspan="2" rowspan="2">VALUES OF SPECTRAL AND SPATIAL PARAMETERS TO OBTAIN DIFFERENT LINE SNRs FOR POINT SOURCES(*)</td><td colspan="3">No. of pixels considered in the detector spectral direction (x)</td><td colspan="2" rowspan="2"></td></tr>
<tr><td><u>Selected line aperture</u>:
$\Delta\lambda = n_{line}\ \sigma_{line}$
$n_{pix,x} = n_{line}\ \sigma_{line} / D$</td><td><u>FWHM of VPH</u>:
$\Delta\lambda = 4D$
$n_{pix,x} = 4$ pixels</td><td><u>In 1 Å</u>:
$\Delta\lambda = 1$ Å
$n_{pix,x} = 1/D$</td></tr>
<tr><td rowspan="3">Source and sky projected area contributing to emission in the projected element</td><td><u>Total source area</u>: $\Omega_{obj}= A_{seeing}$
<u>Sky emission</u>:
- If FWHM $< 2R_{fiber} \Rightarrow \Omega_{obj,sky}=A_{fiber}$
- If FWHM$\geq 2R_{fiber} \Rightarrow \Omega_{obj,sky}= A(N_{fibers})$ (**)</td><td>Total SNR of source, in selected spectral aperture</td><td></td><td></td><td><u>N_{pix} in total projected source in y(**)</u>:
- If FWHM $< 2R_{fiber} \Rightarrow$ $n_{pix,y}=2R_{eff,fiber}/PS$
- If FWHM $\geq 2R_{fiber} \Rightarrow$ $n_{pix,y}=N_{fibers}\times [2\times R_{eff,fiber} /PS]$</td><td rowspan="3">No. of pixels considered in the detector spatial direction (y)</td></tr>
<tr><td><u>Source emission in 1 projected fiber</u>:
- If $FWHM < 2R_{fiber} \Rightarrow \Omega_{obj}=A_{seeing}$
- If $FWHM \geq 2R_{fiber} \Rightarrow \Omega_{obj}=A_{fiber}$
<u>Sky emission</u>: $\Omega_{obj,sky}= A_{fiber}$</td><td>SNR in 1 fiber, in selected spectral aperture
(1 spaxel for spectral aperture)</td><td>SNR in 1 fiber, per FWHM of VPH
(1 voxel)</td><td>SNR in 1 fiber, per Å</td><td><u>N_{pix} in 1 spaxel in y (4 y-pixels)</u>:
$n_{pix,y}=2R_{eff,fiber}/PS = 4$ pixels</td></tr>
<tr><td><u>1 arcsec²</u>:
- If $A_{obj} < 1$ arcsec² $\Rightarrow \Omega_{obj}=A_{obj}$
- If $A_{obj} \geq 1$ arcsec² $\Rightarrow \Omega_{obj}=1$ arcsec²
<u>Sky emission</u>: $\Omega_{obj,sky} = 1$ arcsec²</td><td></td><td></td><td>SNR per arcsec per Å</td><td><u>N_{pix} in 1 y-projected arcsec²</u>:
$n_{pix,y}$ = FLOOR$[1arcsec^2/A_{fiber}]\times [2\times R_{eff,fiber} /PS]$</td></tr>
</table>

		1 x-pixel: $\Delta\lambda = D$, $n_{pix,x} = 1$ pixel		
	Source emission in 1 y-pixel of a projected fiber[***]: - *If FWHM* $< 2R_{fiber} \Rightarrow \Omega_{obj}=A_{seeing}$ - *If FWHM* $\geq 2R_{fiber} \Rightarrow$ S(in 1 y-pixel) = *S(in 1 spaxel /[no. Pixels in one voxel] if uniform distribution.* *If not, 32.82% in the fibers of 100 micron divided into the number of pixels of the FWHM in the spectral direction.* Sky emission: S_{sky}*(in 1 y-pixel)* = S_{sky} (in 1 spaxel) / *[16* pix/spx*]*	SNR in 1 detector pixel (the central one of the voxel, assuming maximum light distribution in the spatial profile, but uniform light distribution in the spectral direction)	1 y-pixel: $n_{pix,y} = 1$ pixel	

Notes:

(*) The flux in a fiber is assumed to be projected uniformly along 4 pixels in the spatial direction of the detector for voxel and spaxel estimates. The spatial projection of the fiber on the detector is thus assumed to be flat, except for estimates on the SNR in one pixel at the center of the voxel. Corrections due to the different distribution of one fiber flux onto each one of these 4 pixels (because of the geometric section of the fiber) could be implemented in future versions (TBD).

(**) The area of all the required fibers to ensure a complete coverage of the source will be noted $A(N_{fibers})$ hereafter. In this case, this area is: $A(N_{fibers})=A_{fiber}\ N_{fibers}$, where N_{fibers} computes the integer number of fibers required to cover the seeing disk. We will note as "FLOOR" to the function that returns the nearest and highest integer of a given decimal value, then: N_{fibers} = FLOOR(A_{seeing}/A_{fiber}).

(***) The signal in one detector pixel is computed from the signal in one voxel, considering that the light distribution in the spatial profile of a voxel has a maximum of flux in its central pixel of 32.82% in the fibers of 100 micron, for all the pixels in the voxel in the spectral direction.

Multi Espectrógrafo en GTC de Alta Resolución para Astronomía

Table 10*: Values assigned to different photometric parameters in order to derive the output line SNRs provided by the MEGARA ETC for extended sources.*

VALUES OF SPECTRAL AND SPATIAL PARAMETERS TO OBTAIN DIFFERENT LINE SNRs FOR EXTENDED SOURCES(*)		**No. of pixels considered in the detector spectral direction (x)**				
		Selected line aperture: $\Delta\lambda = n_{line}\ \sigma_{line}$ $n_{pix,x} = n_{line}\ \sigma_{line} / D$	FWHM of VPH: $\Delta\lambda = 4D$ $n_{pix,x} = 4$ pixels	In 1 Å: $\Delta\lambda = 1$ Å $n_{pix,x} = 1/D$		
Source and sky projected area contributing to emission in the projected element considered	Total source area: $\Omega_{obj} = A_{obj}$ (user input) Sky emission(**): $\Omega_{obj,sky} = A(N_{fibers})$	Total SNR of source, in selected spectral aperture			N_{pix} in total projected source in y(**): - If FWHM < $2R_{fiber} \Rightarrow$ $n_{pix,y} = 2R_{eff,fiber}/PS$ - If FWHM $\geq 2R_{fiber} \Rightarrow$ $n_{pix,y} = N_{fibers} \times [2\times R_{eff,fiber}/PS]$	**No. of pixels considered in the detector spatial direction (y)**
	Source emission in 1 projected fiber: $\Omega_{obj} = A_{fiber}$ Sky emission: $\Omega_{obj,sky} = A_{fiber}$	SNR in 1 fiber, in selected spectral aperture **(1 spaxel for spectral aperture)**	SNR in 1 fiber, per FWHM of VPH **(1 voxel)**	SNR in 1 fiber, per Å	N_{pix} in 1 spaxel in y (4 y-pixels): $n_{pix,y} = 2R_{eff,fiber}/PS = 4$ pixels	
	Emission in 1 arcsec²: - If $A_{obj} < 1$ arcsec² $\Rightarrow \Omega_{obj} = A_{obj}$ - If $A_{obj} \geq 1$ arcsec² $\Rightarrow \Omega_{obj} = 1\ arcsec^2$ Sky emission: $\Omega_{obj,sky} = 1$ arcsec²	SNR per arcsec², in selected spectral aperture		SNR per arcsec per Å	N_{pix} in 1 y-projected arcsec²: $n_{pix,y} =$ FLOOR$[1arcsec^2/A_{fiber}] \times [2\times R_{eff,fiber}/PS]$	
		1 x-pixel: $\Delta\lambda = D$				

		$n_{pix,x} = 1$		
	Source emission in 1 y-pixel of a projected fiber(***): - *If FWHM* $< 2R_{fiber} \Rightarrow \Omega_{obj}=A_{seeing}$ - *If FWHM* $\geq 2R_{fiber} \Rightarrow$ S*(in 1 y-pixel) = S(in 1 spaxel /[no. Pixels in one voxel] if uniform distribution.* *If not, 32.82% in the fibers of 100 micron divided into the number of pixels of the FWHM in the spectral direction.* Sky emission: S_{sky}*(in 1 y-pixel) =* S_{sky} *(in 1 spaxel)/[16* pix/spx*]*	SNR in 1 detector pixel	1 y-pixel: $n_{pix,y} = 1$	

Notes:

(*) The projected area of the extended source is assumed to be circular.

(**) The area of all the required fibers to ensure a complete coverage of the source will be noted $A(N_{fibers})$ hereafter. In this case, this area is: $A(N_{fibers})=A_{fiber}\ N_{fibers}$, where N_{fibers} computes the integer number of fibers required to cover the source. We will note as "FLOOR" to the function that returns the nearest and highest integer of a given decimal value, then: N_{fibers} = FLOOR(A_{obj}/A_{fiber}).

(***) In this case, the total integer number of fibers required to cover a seeing disk is also assumed: $A(N'_{fibers})=A_{fiber}\ N'_{fibers}$, where now N'_{fibers}=FLOOR(A_{seeing}/A_{fiber}).

8. MEGARA EXPECTED PERFORMANCE

8.1. Limiting magnitudes and fluxes

In *Table 11* we show the limiting magnitudes and fluxes to get SNR=10 in one MEGARA voxel, considering 1 hour of exposure time, obtained with the MEGARA ETC v.1.0.0 in all the proposed VPHs. The input spectrum is assumed to be flat.

	Continuum limiting V-band magnitudes(*) to get SNR=10 in one voxel of on-target spaxel C for t_{exp}=3600 s		Line limiting fluxes(*),(***) to get SNR=10 in one voxel for t_{exp}=3600 s	
VPH in LCB or MOS mode	Point source (mag)	Extended source(**) (mag/arcsec^2)	Point source (erg/s/cm^2/Å)	Extended source(**) (erg/s/cm^2/Å/arcsec^2)
HR-R	22.1	21.2	9.9e-19	5.2e-18
HR-I	21.5	20.6	8.1e-19	4.3e-18
MR-U	21.0	20.1	2.4e-18	1.3e-17
MR-UB	21.4	20.5	1.8e-18	9.7e-18
MR-B	21.6	20.7	1.7e-18	8.7e-18
MR-G	22.0	21.1	1.3e-18	6.7e-18
MR-V	22.0	21.1	1.4e-18	7.2e-18
MR-VR	22.3	21.4	1.2e-18	6.0e-18
MR-R	22.1	21.1	1.1e-18	6.0e-18
MR-RI	21.7	20.7	1.1e-18	5.8e-18
MR-I	21.9	21.0	7.3e-19	3.8e-18
MR-Z	22.2	21.3	7.6e-19	4.0e-18
LR-U	21.7	20.8	2.5e-18	1.3e-17
LR-B	22.3	21.4	1.6e-18	8.2e-18
LR-V	22.8	21.8	1.1e-18	6.1e-18
LR-R	23.1	22.2	8.8e-19	4.7e-18
LR-I	22.1	21.2	6.9e-19	3.6e-18
LR-Z	22.5	21.6	8.3e-19	4.4e-18

Notes:
(*) Assuming dark night with seeing of *FWHM(X=1) = 0.5"* at zenith and *X=1*.
Total coverage in one pointing (overheads are not being considered). Number of sky fibers set to default in each mode.
(**) Assuming target size = 1arcsec^2.
(***) Assuming non-resolved lines (i.e., FWHM set by the VPH), and a line wavelength placed at the center of the VPH wavelength range. Negligible continuum assumed: V(continuum)=30 mag. Line aperture=1. Continuum aperture=1000.

***Table 11:** MEGARA expected performance in LCB/MOS mode.*

MEGARA is expected to detect point sources with SNR=10 in one voxel with a continuum magnitude[11] V=22.7, 23.1, and 23.7 mag in high-, medium-, and low-resolution respectively, in one hour in the wavelength range covered by the *R*-band. Similar performances are expected in the *V* band, and ~0.7 mag brighter in the *B* range. The performance in both extremes of the total wavelength range covered by MEGARA is a bit lower (see *Figure 3*), due to the lower total efficiency expected in them (this affects to the *U* and *I*-band ranges, consult *Table 11*). For extended sources, MEGARA is expected to reach SNR=10 in one voxel for sources as faint as V=21.2, 21.6, and 22.2 mag/arcsec^2 in 1h-long exposures.

MEGARA is expected to detect line fluxes of point sources with SNR=10 in one voxel as faint as *f*=4.4e-18, 5.0e-18, and 4.2e-18 c.g.s. in high-, medium-, and low-resolution respectively, for an exposure of 1h, at the central wavelength of the VPHs HR-R, MR-R, and LR-R respectively. For extended sources, the limiting fluxes for SNR=10 rise by a factor of ×4 approximately.

[11] All magnitudes in the MEGARA ETC and in this user guide are in the Vega system.

9. APPENDIX

9.1. Comparison with other existing facilities

GTC+MEGARA shall fill a gap currently existing of a IFS facility providing high spectral resolution, wide FoV, and high sensitivity at the same time (see the "MEGARA Detailed Design: Instrument Overview" document). This makes difficult to compare the expected performance of MEGARA with other facilities, as no instrument with capabilities similar to those of MEGARA exists or is under design. Therefore, we give a comparison below of the improved performance expected for the MEGARA LCB, as compared to the configurations of some instruments providing similar spectral resolutions (Gemini/GMOS, CAHA/PPAK, VLT/FLAMES, and VLT/XSHOOTER). Analogous spatial and spectral resolution elements have been assumed in both focal planes.

GMOS are two twin spectrographs at both 8.1m Gemini telescopes, which offer long-slit, multi-object and fiber-fed IFS capabilities[12]. With a FoV smaller than MEGARA LCB by a factor of 4 and a similar wavelength range, each GMOS spectrograph provides better spatial resolution (down to 0.08"/pixel), but lower maximum spectral resolution than MEGARA (see *Table 12*). GMOS spectrographs offer a configuration with a dispersion and wavelength coverage similar to that of the LR-V VPH of MEGARA (~0.26 Å/pixel): the grating B1200 combined with the OG515 filter. We have used the GMOS ETC[13] in order to compare the output SNRs obtained with this configuration with that obtained with MEGARA LCB using the LR-V VPH in equivalent physical elements onto the detectors of both instruments. Accounting for the similar transmissions of both instruments and their different plate scales (which imply that the SNR obtained with MEGARA at each detector pixel is a factor of ~8.5 higher than that of GMOS just because of the ratio between their sky-projected fiber diameters), we have found that the obtained SNRs are compatible with a better performance by MEGARA by ~25-30% in SNR, for point and extended sources, as well as for continuum and line cases. This improvement is basically due to the higher collecting area of GTC compared to that of the Gemini telescope. However, note that both instruments offer different capabilities: while GMOS provides high spatial resolution, low spectral resolution, and a small FoV, MEGARA will provide intermediate spatial resolution, low-to-high spectral resolution, and a wider FoV. Hence, although each instrument is optimized for different scientific purposes, GTC+MEGARA will be slightly more efficient than GMOS.

PPAK is a fiber-IFU mounted at the 3.5m telescope of Calar Alto Observatory (CAHA). With a FoV wider than the one of the MEGARA LCB by a factor of ~25 and covering the same wavelength range, their fibers are wider by more than a factor of ×4 than those of the LCB[14]

[12] GMOS Integral Field Spectroscopy, Gemini Observatory web pages: http://www.gemini.edu/node/10625?q=node/10372

[13] GMOS integration time calculator. M. Dillman, 2009: http://sciopsedit.gemini.edu/sciops/instruments/integration-time-calculators/gmosn-itc

[14] PMAS Technical Overview, CAHA web pages: http://www.caha.es/pmas/PMAS_OVERVIEW/pmas_overview.html#IFU

(see *Table 12*). Comparing the output SNRs in equivalent cases for both instruments for a point source[15] and considering that the SNR at each detector pixel of PPAK is a factor of ×4 higher than in one projected pixel of the MEGARA LCB (because of the bigger projected section of a PPAK fiber), we have checked that MEGARA will improve the SNR obtained with PPAK by a factor of ~3.5, considering analogous spatial and spectral elements in both instruments. The different collecting areas of GTC and CAHA 3.5m telescopes are responsible of a factor of ×2.9, while the better transmission expected for MEGARA (nearly twice that of PPAK in the whole wavelength range) explains the rest of SNR enhancement. Therefore, MEGARA will achieve a given SNR per arcsec and per Å in a given source using 8 times less exposure time than PPAK, providing better spatial and spectral resolutions at the same time (here we do not account for the 3-pointings dithering required by PPAK to fill the gaps between fibers, which would rise this factor even further).

	GTC/ MEGARA LCB	Gemini-N/ GMOS IFU	CAHA3.5m/ PPAK	VLT/ FLAMES (GIRAFFE +ARGUS IFU)	VLT/ XSHOOTER
Telescope Ø (m)	10.4	8.1	3.5	8.2	8.2
FoV	12.5"x11.3"	5"×7"	1.2'×1'	11.5"×7.3"	4"×1.8"
Spatial Resolution	0.62"/fibre	0.31"/fibre	2.7"/fibre	0.52"/fibre	0.16"/pixel
Spectral resolution	5500 - 17,000	6000	3000 - 14,000	11,000 -35,000	3000 - 18,000
Wavelength range (Å)	3700 - 9700	4000 - 11,000	2500 - 10,000	3700 - 9500	3000 - 25,000

Table 12: *Comparison of the main characteristics of GTC+MEGARA with those offered by other existing facilities.*

FLAMES/GIRAFFE is a spectrograph located at one of the 8.2m telescopes of VLT (the UT2), that allows an IFU configuration through ARGUS, an array of micro-lenses feeding a bundle of fibers. FLAMES can do medium- and high-resolution spectroscopy (up to R=46,000) in small FoV at optical wavelengths, so it is not directly comparable to MEGARA either[16]. The spatial resolution is slightly better than that of MEGARA LCB (see *Table 12*) and the transmission is worse by a factor of ×2, depending on the wavelength. FLAMES/GIRAFFE+ARGUS offers two FoVs, the widest being smaller than the MEGARA LCB. One of its configurations (LR5) provides a similar dispersion and wavelength coverage as MEGARA LCB with the MR-V VPH. Comparing the output SNRs obtained with both instruments in a point source and

[15] CAHA/PMAS exposure time calculator. S. Sánchez, 2006:
http://www.caha.es/sanchez/pmas/calculator/pmas_etc.php

[16] FLAMES/GIRAFFE Spectrograph description, VLT web pages:
http://www.eso.org/sci/facilities/paranal/instruments/flames/inst/Giraffe.html

accounting for the different projected fiber sizes[17], we have found that the MEGARA would provide an enhancement by a factor of ~1.6 in the SNR of equal resolution elements. This improvement is due to the difference of telescope collecting areas and to the higher transmission expected for MEGARA, basically. Therefore, even being facilities providing different and complementary capabilities, GTC+MEGARA is slightly more efficient than the VLT instrument GIRAFFE+ARGUS in analogous cases.

XSHOOTER is a multi-wavelength medium resolution spectrograph mounted at the VLT UT2 Cassegrain focus[18]. It consists of 3 arms, each one being an independent cross dispersed echelle spectrograph with optimized optics, dispersive elements, and detectors for different wavelength ranges. The incoming light is split into the three different spectrographs/arms through 2 dichroics. The two arms that overlap in spectral range with that of MEGARA are the UVB (300-559.5 nm) and the VIS (559.5-1024 nm) arms. XSHOOTER covers ~20 times less area in one pointing than the MEGARA LCB, but has better spatial resolution (see *Table 12*). It offers spectral resolutions very similar to those offered by MEGARA for wavelengths longer than 5600 Å (R~5400-18,200 in VIS), but not as high in the blue range (R~3300-9900 in UVB). We have compared the total SNRs in a spectral resolution element expected for an A0V star with V=20 mag obtained with both instruments for 1 hour of exposure time, using configurations that provide equivalent spectral resolutions at similar wavelengths[19]. We have assumed that the observations have been taken during a dark night with a seeing FWHM=1.0" at airmass X=1. The results in *Table 13* show that GTC+MEGARA shall provide SNRs per Å and arcsec in a given source a factor of ~2-3 higher than XSHOOTER for analogous cases, which is a reasonable result accounting for the difference in telescope collecting areas and in total efficiency (higher in MEGARA by a factor of ~2-5 typically). Therefore, GTC+MEGARA shall cover much wider area than XSHOOTER, providing higher spectral resolution and higher expected performance, although the later one offers a factor of ~3-4 better spatial resolution than the former one.

In conclusion, the expected performance of GTC/MEGARA as simulated by the MEGARA ETC demonstrates that it shall provide with unique spectroscopic capabilities to GTC in the whole optical range, not covered by any other existing facility at the present, that will allow the scientific community to carry out high-quality observations for high-impact scientific projects.

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[17] FLAMES/GIRAFFE Exposure Time Calculator, version 3.2.7 (March 4, 2009): http://www.eso.org/observing/etc/bin/gen/forms?INS.NAME=GIRAFFE++INS.MODE=spectro

[18] VLT/XSHOOTER ESO webpage: http://www.eso.org/sci/facilities/paranal/instruments/xshooter/index.html

[19] VLT/XSHOOTER Echelle Spectroscopy Mode, version 3.2.13 Exposure Time Calculator: http://www.eso.org/observing/etc/bin/gen/form?INS.NAME=X-SHOOTER+INS.MODE=spectro

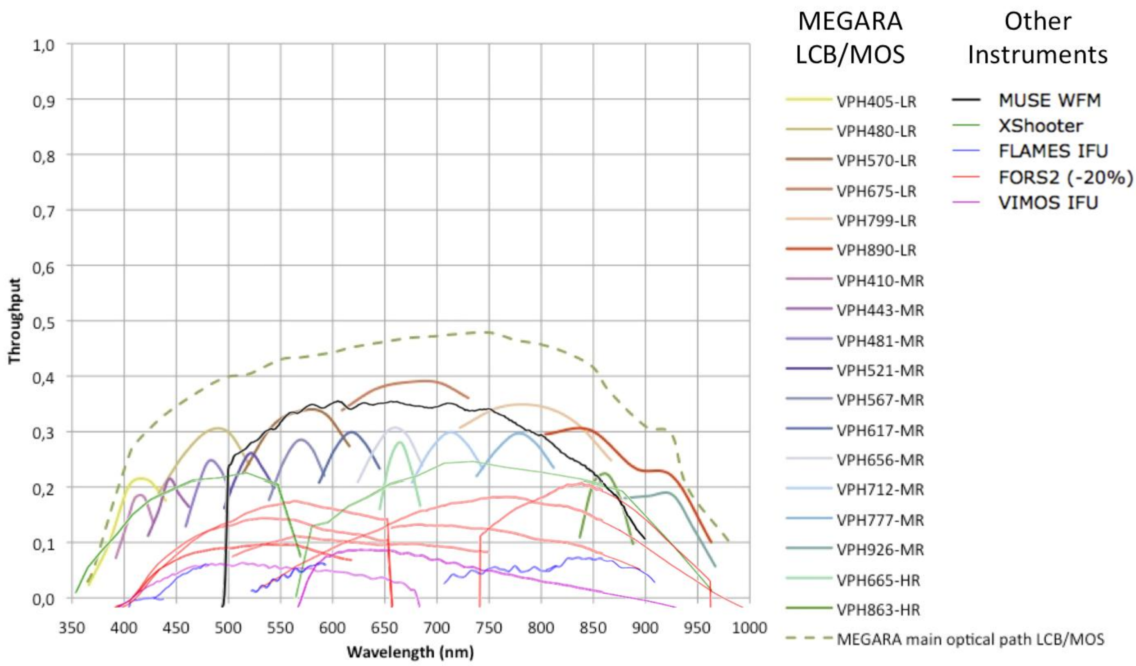

***Figure 15:** Comparison of GTC/MEGARA throughput at different wavelengths with other existing facilities.*

VLT+XSHOOTER configuration				**GTC+MEGARA LCB equivalent configuration**				**MEGARA-to-XSHOOTER improvement factor of the SNR in 1 spectral FWHM**	
VIS arm R = 6700 @ 5595 – 10,240 Å slit =1.2" - FWHM=7.9 pix - 1×1binning				VPHs R=6250 @ 5595 – 10,240 Å Spectral FWHM = 3.5 pix					
λ_{Blaze} (Å)	SNR in 1 spectral pixel	SNR in 1 spectral FWHM	Eff (%)	VPHs	$\lambda_{central}$ (Å)	SNR in 1 spectral FWHM	Eff (%)	Expected from differences in telescope diameter and efficiency	Obtained from the estimates of ETCs
6821	11	31	11	LR-R	6749	97	35	×2.2	×3.1
8602	8	21	11	LR-I	8650	55	15	×1.4	×2.6
VIS arm R = 10,600 @ 5595 – 10,240 Å slit =0.7" - FWHM=4.9 pix - 1×1binning				VPHs R=11,000 @ 5595 – 10,240 Å range Spectral FWHM = 3.5 pix					
λ_{Blaze} (Å)	SNR in 1 spectral pixel	SNR in 1 spectral FWHM	Eff (%)	VPHs	$\lambda_{central}$ (Å)	SNR in 1 spectral FWHM	Eff (%)	Expected from differences in telescope diameter and efficiency	Obtained from the estimates of ETCs

5680	9	20	5.7	MR-V	5667	63	35	×2.8	×3.2
6295	9	20	6.8	MR-VR	6170	63	35	×2.5	×3.2
UVB arm R = 6200 @ 3000 – 5595 Å slit=0.8" - FWHM=5.2 pix - 1×1 binning				VPHs R=6250 @ 3000 – 5595 Å Spectral FWHM = 3.5 pix					
λ_{Blaze} (Å)	SNR in 1 spectral pixel	SNR in 1 spectral FWHM	Eff (%)	VPHs	$\lambda_{central}$ (Å)	SNR in 1 spectral FWHM	Eff (%)	Expected from differences in telescope diameter and efficiency	Obtained from the estimates of ETCs
4145	20	45	8.1	LR-U	4051	36	6	×1.0	×0.8
4660	20	45	8.5	LR-B	4800	70	10	×1.4	×1.5
5560	11	25	3	LR-V	5700	92	35	×4.0	×4.0

Comments to Table:

1. The SNRs are computed integrating spatially for the whole source.
2. The MEGARA spectral resolutions are computed using the spectral FWHM of the MEGARA LCB as $\delta\lambda$.
3. The efficiencies (Eff) of XSHOOTER refer to the total efficiency, including the slit loss and atmospheric extinction. The efficiencies of MEGARA include telescope+instrument flux losses and atmospheric transmission at La Palma observatory.
4. A dark night with a seeing FWHM=1.0” and airmass X=1 have been assumed in both cases.
5. The improvement factors of the SNR obtained with MEGARA compared to XSHOOTER have been estimated in two ways: accounting for the efficiency and telescope diameter differences, and considering the estimates obtained with the ETCs of both instruments (compare the two last columns of the Table). The agreement between both estimates is worse at redder wavelengths. This is due to the existence of noticeable atmospheric absorption lines at longer wavelengths, considered differently in each ETC.

Table 13: *Comparison of the continuum SNR expected for a point source with V=20 mag, for 1 hour of integration time in VLT+XSHOOTER and GTC+MEGARA, using configurations with similar spectral resolutions at similar characteristic wavelengths.*

10. INDEX OF FIGURES

11. INDEX OF TABLES